Volume 4, Number 5
ISSN: 0869-5938

September - October 1996

STRATIGRAPHY AND GEOLOGICAL CORRELATION

Official English Translation of *Stratigrafiya. Geologicheskaya Korrelyatsiya*

Editor-in-Chief
Boris S. Sokolov

Academician, Russian Academy of Sciences
counsellor of the Presidium of the Russian Academy of Sciences

Journal of the Fundamental and Applied Aspects of Stratigraphy and the Correlation of Geologic Events and Processes in Time and Space

МАИК НАУКА/INTERPERIODICA PUBLISHING

Stratigraphy and Geological Correlation

(Stratigrafiya. Geologicheskaya Korrelyatsiya)

ISSN: 0869-5938

Editor-in-Chief
Boris S. Sokolov
Academician, Russian Academy of Sciences,
Counsellor of the Presidium of the Russian Academy of Sciences

Address for correspondence: Staromonetnyi per. 22, Moscow 109180 Russia
Phones: 7-(095) 231-2164; Fax: 7-(095) 233-5590.

Deputy Editor-in-Chief
Mikhail A. Semikhatov
Member of the Russian Academy of Sciences
Head of Laboratory, Geological Institute,
Russian Academy of Sciences

Assistant Editor
Aleksei B. Herman
Senior Scientist,
Geological Institute,
Russian Academy of Sciences

EDITORIAL BOARD

Mikhail A. Akhmet'ev
Dr. Sci. (Geol.-Min.),
Head of Laboratory, Geological Institute,
Russian Academy of Sciences

Aleksandr S. Alekseev
Professor, Department of Paleontology,
Moscow State University

Mikhail N. Alekseev
Dr. Sci. (Geol.-Min.),
Chief Scientist, Geological Institute,
Russian Academy of Sciences

Ivan A. Basov
Dr. Sci. (Geol.-Min.),
Deputy Director, Institute of the Lithosphere,
Russian Academy of Sciences

Michael G. Basset
Professor, National Museum of Wales,
Cardiff, UK

William A. Berggren
Professor, Department of Geology and
Geophysics, Woods Hole Oceanographic
Institute, USA

Elena V. Bibikova
Dr. Sci. (Geol.-Min.), Chief Scientist,
Vernadskii Institute of Geochemistry
and Analytical Chemistry,
Russian Academy of Sciences

Nikita A. Bogdanov
Corresponding Member of the Russian Academy
of Sciences, Director, Institute of the
Lithosphere, Russian Academy of Sciences

Kiyotaka Chinzei
Professor, Institute of Geology,
University of Tokyo, Tokyo, Japan

Nikolai M. Chumakov
Dr. Sci. (Geol.-Min.),
Chief Scientist, Geological Institute,
Russian Academy of Sciences

Yurii B. Gladenkov
Dr. Sci. (Geol.-Min.),
Deputy Director, Geological Institute,
Russian Academy of Sciences

Dmitrii L. Kaljo
Professor, Institute of Geology, Tallinn, Estonia

Victor E. Khain
Member of the Russian Academy of Sciences,
Chief Scientist, Institute of the Lithosphere,
Russian Academy of Sciences

Lidiya A. Nevesskaya
Dr. Sci. (Biol.), Laboratory Chief, Institute of
Paleontology, Russian Academy of Sciences

Aleksandr G. Ponomarenko
Dr. Sci. (Biol.), Chief Scientist, Institute of
Paleontology, Russian Academy of Sciences

Jurgen Remane
Professor, Institute de Géologie,
Université de Neuchâtel, Switzerland

Aleksei Yu. Rozanov
Dr. Sci. (Geol.-Min.),
Director, Institute of Paleontology,
Russian Academy of Sciences

Boris A. Sokolov
Dr. Sci. (Geol.-Min.),
Professor, Dean, Faculty of Geology,
Moscow State University

Otto Walliser
Professor,
Göttingen University, Göttingen, Germany

Sun Weigo
Professor, Nanjing Institute of Geology
and Paleontology, Academia Sinica, China

Victor A. Zakharov
Dr. Sci. (Geol.-Min.),
Head of Laboratory, Institute of Geology,
Geophysics, and Mineralogy,
Siberian Branch, Russian Academy
of Sciences, Novosibirsk

Aleksandr I. Zhamoida
Corresponding Member of the Russian Academy
of Sciences, Russian Geological Institute,
St. Petersburg

Staff Editor Tamara V. Trishkina
Editor of the English Translation Anatolii Ya. Sharas'kin, Dr. Sci. (Geol.-Min.)

SCOPE

Stratigraphy and Geological Correlation (Stratigrafiya. Geologicheskaya Korrelyatsiya) is the only journal in the world designed to provide comprehensive coverage of the fundamental and applied aspects of stratigraphy and the correlation of geological events and processes in time and space. Articles are based on the results of multidisciplinary research, and are directed toward researchers, university professors, students, and geologists interested in understanding stratigraphy and the chronological features of the world's geological record.

Stratigraphy and Geological Correlation is abstracted and/or indexed in *Petroleum Abstracts*, Research Alert, SciSearch, *Current Contents* (Physical, Chemical, and Earth Sciences) and *World Translations Index*.

SUBSCRIPTION OFFICE
INTERPERIODICA
P.O. BOX 1831, BIRMINGHAM, AL 35201-1831 USA
PHONE: (800) 633-4931; (205) 995-1567 (outside US and Canada); FAX: (205) 995-1588

PUBLISHER
МАИК НАУКА/INTERPERIODICA PUBLISHING
PROFSOYUZNAYA UL. 90, MOSCOW, 117864 RUSSIA
PHONE: 7-(095) 336-1600; FAX: 7-(095) 336-0666

SUBSCRIPTION PRICES (1996, Volume 4, 6 issues)
US $699.00 (North America), $805.00 (other). A 5% discount is given on 2-year orders. Subscriptions may be entered at any time. Orders may be placed at agencies or directly. 5% discount to all subscription agencies. Cancellations not allowed except for duplicate payment. Prepayment required. Advance payment required in US$/US bank. MasterCard/Visa accepted. Checks payable to *Stratigraphy and Geological Correlation* or Interperiodica.

Stratigraphy and Geological Correlation (ISSN: 0869-5938) is published bimonthly for (US dollars) $699.00 (North America), outside North America $805.00 per year by MAIK Nauka/Interperiodica Publishing, 5724 Hwy. 280 East, Birmingham, Alabama 35242-5724 USA. Second Class Postage Paid at Birmingham, Alabama. POSTMASTER: Send address changes to *Stratigraphy and Geological Correlation*, P.O. Box 1831, Birmingham, Alabama 35201 USA.

Journal founded in 1993.

Original Russian Edition Copyright © 1996 by the Russian Academy of Sciences
and the Division of Geology, Geophysics, Geochemistry, and Mining Sciences.
English Translation Copyright © 1996 by МАИК Наука/Interperiodica Publishing (Russia).

Contents

Vol. 4, No. 5, 1996

Simultaneous English language translation of the journal is available from МАИК Наука/Interperiodica Publishing (Russia). *Stratigraphy and Geological Correlation* ISSN 0869-5938.

Eustatic Events and Black Shale Sedimentation at the Cambrian–Ordovician Boundary
L. E. Popov and T. N. Koren' 419

Carboniferous-Permian Boundary as Indicated by Conodonts
I. S. Barskov and A. N. Reimers 428

Permian Deposits in the Novaya Zemlya Islands
L. G. Povysheva and V. I. Ustritskii 440

New Data on the Jurassic Phytostratigraphy in Kazakhstan
A. I. Kirichkova and M. P. Doludenko 450

Chronology and Biochores of Callovian Ammonites from Mangyshlak
Yu. S. Repin and N. Rashwan 467

Paleogene Climatic Fluctuations and Biotic Migrations in the North Pacific
V. N. Ben'yamovskii and Yu. B. Gladenkov 480

The Oligocene–Early Miocene Floral Assemblages from Western Siberia
V. S. Volkova and I. A. Kul'kova 496

Second Edition of the International Stratigraphic Guide
A. I. Zhamoida 506

Brief Communications

Early Holocene Fossil Insects Fauna and Natural Environments in the Ural River Lower Course
F. G. Bidashko and Yu. V. Petrenko 514

The Double Carbonate Thermometer as a Tool for Correlation and Stratigraphic Subdivision of the Quaternary Deposits
L. A. Dorofeeva, R. E. Prilutskii, and V. K. Shkatova 517

Chronicle

Awards of NAUKA Publishing Company for Best Publications in 1995 523

Stratigraphy and Geological Correlation, Vol. 4, No. 5, 1996, pp. 419–427. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 5, 1996, pp. 3–12.
Original Russian Text Copyright © 1996 by Popov, Koren'.
English Translation Copyright © 1996 by МАИК Наука/Interperiodica Publishing (Russia).

Eustatic Events and Black Shale Sedimentation at the Cambrian–Ordovician Boundary

L. E. Popov and T. N. Koren'

All-Russia Research Geological Institute, Srednii pr. 74, St. Petersburg, 199026 Russia

Received October 25, 1994

Abstract—The unstable sea-level position in the Cambrian–Ordovician boundary interval resulted in several consequent eustatic minima. Among them, the Lange Ranch (the base of the *proavus* Zone), *Acerocare* (the base of the Tremadocian, or beginning of the *lindsromi* Zone), Black Mountain (the early Tremadocian, or the base of the *angulatus/rotundatus* Zone), *Peltocare* (the latest early Tremadocian, near the base of the *deltifer* Zone) and *Ceratopyge* (the end of the Tremadocian and the *deltifer* Zone) events are recognizable in the diverse spectrum of shelf continental facies. The Lange Ranch, Black Mountain and *Ceratopyge* events were followed by transgressions of different extents, which resulted in a widespread black shale sedimentation in different shelf zones. Paleozoogeographic features and distribution of characteristic litho- and biofacies at the Cambrian–Ordovician and Tremadocian–Arenigian boundaries are analyzed to reveal the possible effect of the climatic factor and the character of biotic changes. The reconstructed paleozoogeography and biofacial zonations are based on trilobites for the Late Cambrian and early Tremadocian, brachiopods for the Arenigian, and graptolites and conodonts for the entire interval discussed.

Key words: *eustatic minimum, event, Cambrian, Ordovician, graptolites, brachiopods, conodonts, trilobites, climate, biofacies, black shale sedimentation, paleogeography, glaciation.*

A conclusion on the unstable sea-level position at the Cambrian–Ordovician boundary was first made through the study of sections of North America, Australia and the China plate (Miller, 1984), and was later confirmed by materials from Baltia and Scandinavia (Nicoll *et al.*, 1992). At present, up to five eustatic minima (Fig. 1) are recognized in continental sections, and at least three of them coincide with substantial faunal reorganizations. Among the major changes in the pelagic biota of this time were the replacement of paraconodonts by euconodonts, and the appearance and wide distribution of nematophore graptoloids, which colonized the planktonic biotopes. These biologic events occurred against the background of maximal distribution of black shale sedimentation on continental margins and shelves. Changes in the benthic fauna were of a stepwise character during the whole Tremadocian. They are marked by changes of dominants and the radical reorganization of the structure of shelf associations, which preceded the most drastic radiation in the Arenigian.

To reveal the possible relationship between biotic and climatic events, one should restore essential environmental parameters, such as the temperature regime, oceanic circulation, and content of oxygen dissolved in sea water, all recorded in accumulated sediments. In recent years, the Ordovician climate was analyzed on the palinspastic basis (Wilde, 1991; Scotese and McKerrow, 1991), though many aspects related to climatic changes at the boundary between the Cambrian and Ordovician remain unclear or controversial.

In this connection, it may be expedient to consider once again the paleozoogeographic features at the end of the Cambrian and the beginning of the Ordovician, as well as the distribution of characteristic litho- and biofacies on cratons during the period of an extremely unstable sea-level position. The implication of the paleolatitudinal control for the distribution of faunal associations, especially on cratons, is well known, which is why they are of great importance as indicators of the paleoclimate. At the same time, deep-water biofaciees of marginal seas, which are considerably less dependent on paleolatitudes, are used for reconstructing the configuration of continental plates (Cocks and Fortey, 1990).

The available material allows a general consideration of two time slices, corresponding to the Cambrian–Ordovician and Tremadocian–Arenigian boundaries. The main difficulty in their comparative analysis is the necessity to use different dominant groups of the benthic fauna, i.e. trilobites for the beginning of the Ordovician and brachiopods for the beginning of the Arenigian. Moreover, the analysis is complicated by the fact that up to now, the boundary of the considered system has not been officially adopted on a global scale. The International Subcomission on the Ordovician Stratigraphy is currently debating the problem on assigning the boundary to the base of one of the con-

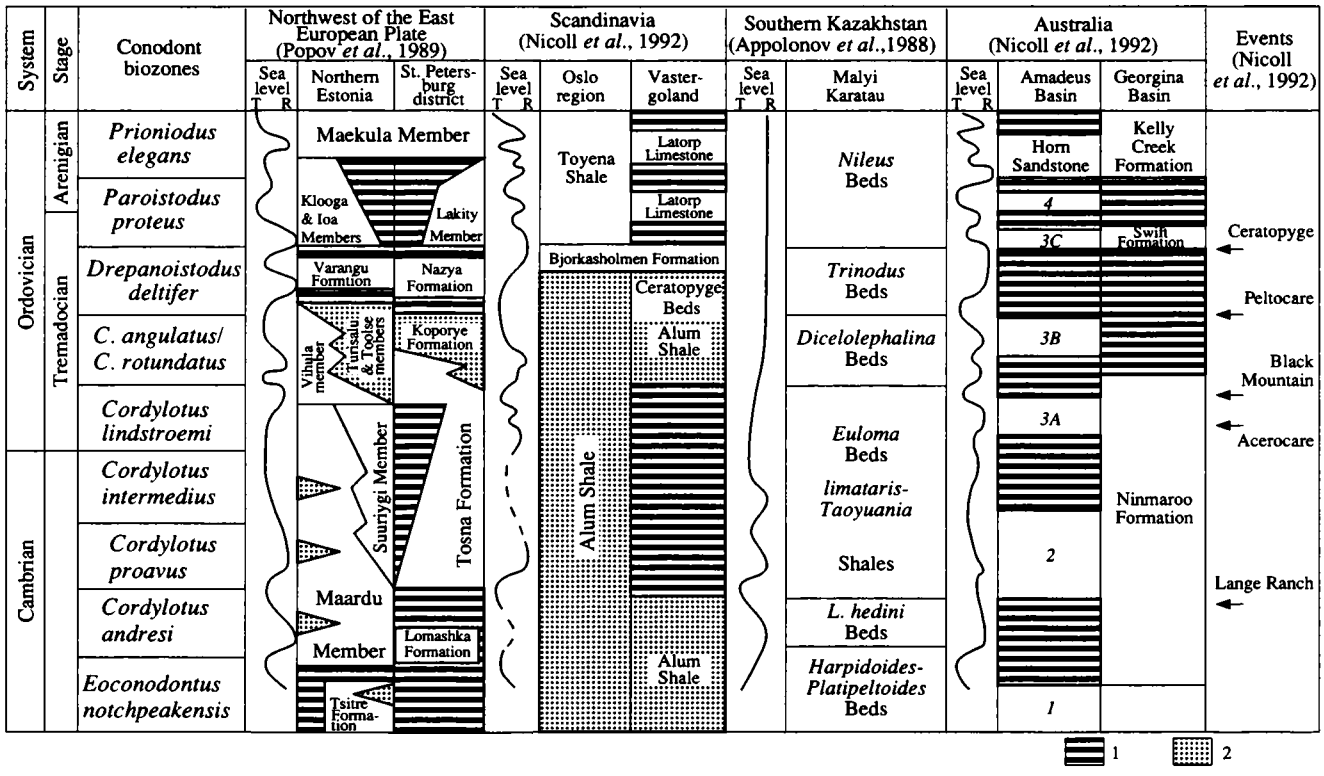


Fig. 1. Curves showing sea-level oscillations and hypothetical eustatic minima at the end of the Late Cambrian, Tremadocian and the beginning of the Arenigian deduced from data on the Cambrian–Ordovician boundary deposits of Baltoscandia, Australia and southern Kazakhstan: (1) hiatuses; (2) levels of black shale sedimentation. In the column for Australia, figures *1*, *2*, *3A*, and so forth, signify numbers of the Pacota Sandstone sequences (Nicoll *et al.*, 1992). Abbrevations: T—transgressions, R—regressions.

odont zones near the first appearance of nematophore graptolites, i.e., to the traditional base of the Tremadocian. In this connection, we use conodont zones to date sedimentological events and to analyze the dynamics of biotic changes in the present work (Miller, 1988; Dubinina, 1991).

GENERAL FEATURES OF PALEOZOOGEOGRAPHY

The climatic situation at the end of the Cambrian–beginning of the Ordovician was dictated by the concentration of major continents in the southern hemisphere (Scotese and McKerrow, 1991; Cocks and Fortey, 1990). The Gondwanan supercontinent extended from subequatorial northern latitudes to the South Pole. Medium-sized continents, such as Laurentia (the North American Plate), and Angarida (the Siberian Plate), were located in low latitudes, whereas Baltia (the East European Plate), was within middle, and partially high latitudes. The Avalonian microcontinent included the eastern part of Newfoundland, the eastern coast of North America, England, Wales, southern Ireland and northwestern France. The microcontinent was separated from the African part of Gondwana only in the Tremadocian, and resided in high latitudes not far from it in the early Arenigian. The northern hemisphere was occupied by the vast Boreal Ocean, the data on which are obscure. The ocean was presumably surrounded by a system of island arcs located along the northern margins of Gondwana, Angarida and Laurentia. A major island-arc system, the Kipchak island arc (Sengor *et al.*, 1993), was probably between Angarida and Baltia. It is conceivable that the Paleozoic terranes of the Mongol–Okhotsk foldbelt, Altai, eastern and northern parts of central Kazakhstan, are fragments of this island arc. As to the Paleozoic terranes in the southern part of central Kazakhstan and northern Tien Shan, the southwestern polarity of the early Paleozoic subduction in modern coordinates (Koren' *et al.*, 1993) is opposite to that suggested in the reconstructions made by Sengor and other researchers. Most likely, these terranes did not belong to the Kipchak island arc at least until the Silurian. A great similarity in the structure of the Precambrian–Cambrian boundary sections in the Lesser Karatau Range and southern China (Rozanov and Sokolov, 1984), as well as the presence of numerous common elements in the Cambrian and Early Ordovician fauna allow us to suggest that at the Cambrian–Ordovician boundary, these terranes were constituents of an island-arc system that surrounded Gondwana.

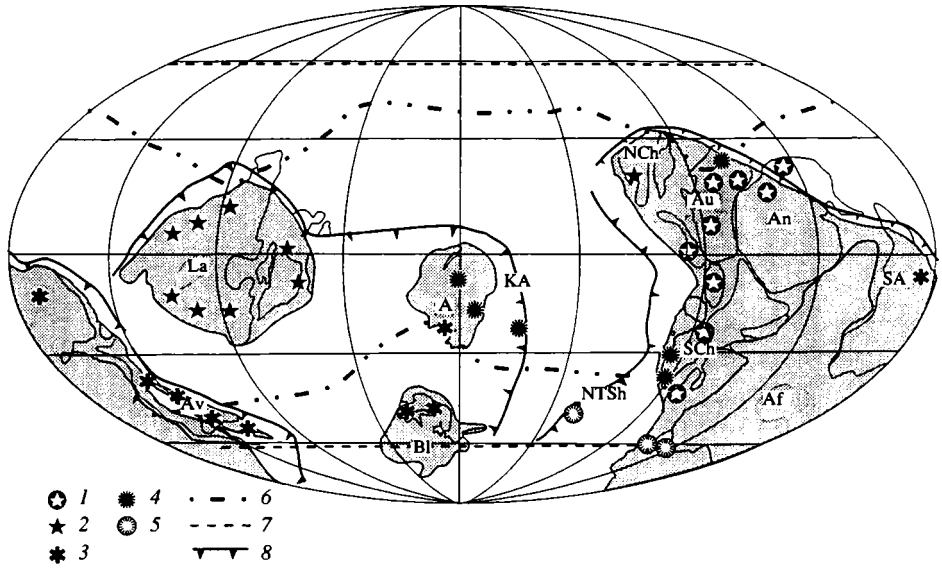


Fig. 2. Paleogeographic distribution of trilobite biofacies at the end of the Late Cambrian (after Shergold, 1988).
(*1*) North China Province (saukiid-tsinaniid and kainellid-leiostegid biofacies of predominantly warm-water type); (*2*) North American Province (tropical dikelocephalid-olenid and histricurid biofacies); (*3*) Baltic Province (relatively cold-water olenid biofacies); (*4*) South China Province (ceratopygid biofacies of relatively cold-water basins in middle latitudes); (*5*) South China Province (altered ceratopygid biofacies of relatively cold-water basins in middle latitudes); (*6*) subtropical convergence; (*7*) polar convergence; (*8*) hypothetical position of active continental margins and volcanic arcs. Basic paleocontinents (Scotese and McKerrow, 1991): La–Laurasia, A—Angarida, Bl—Baltia, Av—Avalonia. Constituents of Gondwana: NCh—North China Plate, SCh—South China Plate, Au—Australia, An—Antarctica, Af—Africa, SA—South America, NTSh—northern Tien Shan, KA—position of the Kipchak island arc (after Sengor *et al.*, 1993).
In this and other figures, the relative position of continental massifs is given after Scotese and McKerrow (1991) with modifications for Baltia after Trench and Tornsvik (1992); the position of the subtropical and polar divergence after Wilde (1991).

For the Late Cambrian–early Tremadocian (the *proavus* and *lindstromi* zones), the known paleozoogeographic reconstructions are based on the analysis of the trilobite fauna (Shergold, 1988; Whittington and Hughes, 1974). Shergold distinguished five provinces of the terminal Cambrian in the distribution of the main trilobite biofacies (Fig. 2). Among them, the Baltic cold-water province occupied the most extensive areas on the periphery of Gondwana and Baltia (the East European platform). The southern and northern China provinces corresponded to temperate and subtropical belts. The warm-water faunas inhabited Laurentia, which resided in the equatorial area. The climatic factor in the abundance of the trilobite biofacies is confirmed by the distribution areas of carbonate accumulation. For the Late Cambrian, these sediments are nearly unknown within the Baltic trilobite province. Brachiopods, especially lingulates, could be another index group, but their paleozoogeography at the end of the Cambrian is still not clearly understood.

The known paleozoogeographic reconstructions lack the detailed biofacial analysis of the distinguished provinces. At present, data on the biofacial zonation are available for Baltia and Laurentia. Diverse warm-water assemblages of endemic trilobites inhabited shallow-water carbonate shelves of Laurentia (Ludwigsen, 1982). The deep shelf and transitional slope areas were inhabited by uniform assemblages dominated by agnostids and olenids. Often, they dwelled in oxygen-depleted settings, where dark-colored carbonate and clayey oozes accumulated.

The Baltic paleobasin may serve as an example of the biofacial zonation characteristic of high latitudes. Dark-colored oozes rich in organic matter accumulated on its periphery from the Late Cambrian as a possible response to the upwelling. Uniform olenid assemblages are confined to these oozes (Martinsson, 1974). Olenids occupied mainly open shelf zones, whereas obolid assemblages of brachiopods inhabited shoals with terrigenous sedimentation, where trilobites were almost completely lacking. This biofacial zonation is traceable with minor changes within the Baltic province from the Late Cambrian to the middle Tremadocian (the *deltifer* Zone). A slight southward displacement of Gondwana was noted at the end of the Tremadocian–beginning of the Arenigian, whereas Baltia gradually moved northward (Figs. 2–4).

A somewhat different paleozoogeographic zonation was set up during the Arenigian, and retained during the greatest interval of the Ordovician (Williams, 1973). The main feature of this zonation is a reduction of distribution areas occupied by the cold-water fauna as

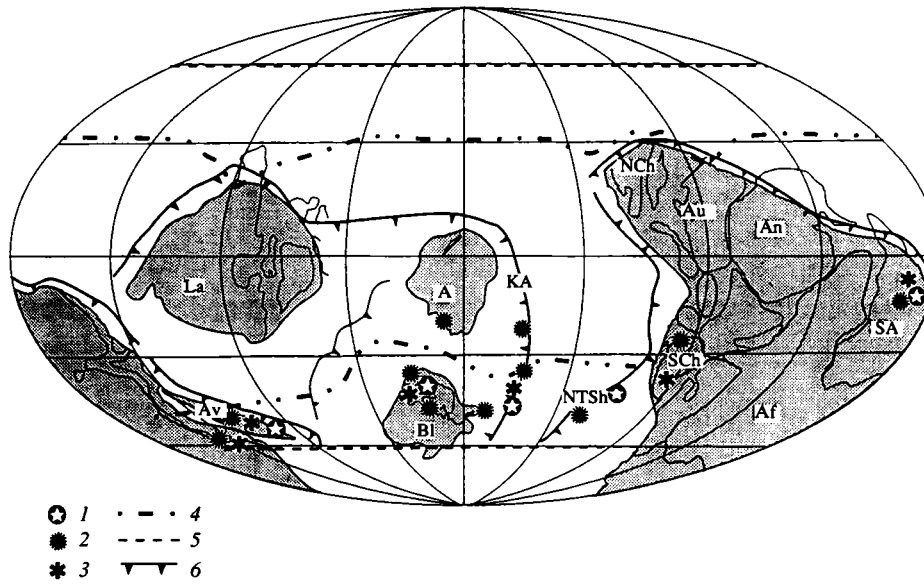


Fig. 3. Paleogeographic distribution of trilobite, graptolite and brachiopod biofacies related to black shale sedimentation areas of the early Tremadician (Erdtmann, 1982; Popov and Holmer, 1994).
(*1*) *Broeggeria* assemblage (brachiopods); (*2*) graptolite biofacies with *Rhabdinopora* ex gr. *flabelliforme*; (*3*) olenid biofacies; (*4*) subtropical convergence; (*5*) polar convergence; (*6*) active continental margins and island arcs. Other symbols as in Fig. 2.

compared to those of the Late Cambrian time. These areas were confined to South American and North African parts of Gondwana, and also to the newly formed Avalonian continent. The migration of a new benthic fauna into Baltia is notable at the end of the Tremadocian–beginning of the Arenigian. Its origin may partially be associated with the south China province (trilobites), although it is cryptogenic in general. The biofacial zonation substantially changes from this time due to an abrupt increase in the diversity of many groups of invertebrates (echinoderms, brachiopods, bryozoans and others). Trilobites cease to have their dominating position, especially in shelf associations.

Inferred paleozoogeographic regularities in the distribution of pelagic taxa of the Late Cambrian–Early Ordovician are based on the analysis of the conodont fauna. Two major provinces can be distinguished: the cold-water area, which included Baltia, the Kazakhstan terranes and the south China part of Gondwana, as well as the warm-water area, which was inhabited by the conodont fauna of Laurentia, north China and Australian parts of Gondwana (Miller, 1984). An intermediate, distinguishable zone was marked by mixed warm-water and cold-water fauna (Dubinina, 1991).

The appearance and wide distribution of nematophore planktonic graptolites (the end of the *intermedius* Zone–beginning of the *lindstromi* Zone; Erdtmann, 1988) were mainly confined to high and middle latitudes that approximately coincide with the cold-water province of conodonts. Only since the Arenigian did the new graptolite fauna spread worldwide with a distinct paleozoogeographic differentiation.

REGRESSIVE–TRANSGRESSIVE CYCLES AND BIOT EVENTS

The transitional interval between the Cambrian and Ordovician (Tremadocian) can be identified as a period of an extremely unstable sea level.

Eustatic changes and related facial and ecological rearrangements are studied mainly on the basis of sediments of epicontinental and marginal seas. Recently, this was supplemented with data on synchronous pelagic biogenic sequences, which are interpreted as abyssal sediments preserved in a modern structure only in ophiolite associations.

The Upper Cambrian sequences are of a regressive structure in many continents. Hiatuses, which are interpreted as markers of eustatic minima and rearrangements in the structure and composition of the biota, are characteristic of the Tremadocian. Among them, the Lange Ranch (Miller, 1984; the end of the Late Cambrian, or the base of the *proavus* Zone), *Acerocare* (Erdtmann, 1986; the base of the Tremadocian, or the lower part of the *lindstromi* Zone), Black Mountain (Miller, 1984; the early Tremadocian, or the base of the *angulatus/rotundatus* Zone), *Peltocare* (the end of the early Tremadocian, the basal *deltifer* Zone) and *Ceratopyge* events (Erdtmann, 1982, 1986; the terminal Tremadocian, the upper *deltifer* Zone) are detectable in the diverse facies of some continents (Baltia, Laurentia,

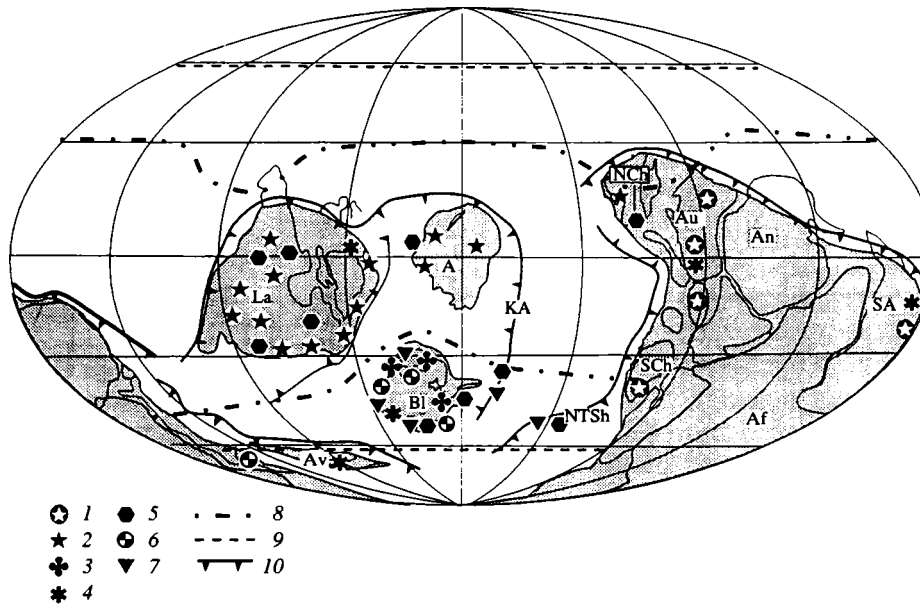


Fig. 4. Paleogeographic distribution of some trilobite and brachiopod biofacies of the early Arenigian (Cocks and Fortey, 1990; Popov and Holmer, 1994).

(*1*) Dikelocephalid biofacies; (*2*) bathyurid biofacies; (*3*) asaphid biofacies; (*4*) olenid biofacies; (*5*) *Clarkella/Tetralobula* assemblage; (*6*) *Thysanotos* assemblage; (*7*) micromorphic lingulate assemblage with *Eoconulus* and *Otariella*; (*8*) subtropical convergence; (*9*) polar convergence; (*10*) active continental margins and island arcs. Other symbols as in Fig. 2.

and Chinese, Australian and South American parts of Gondwana) (Fig. 1). Whether or not the mentioned eustatic minima are parts of isolated cycles is not yet clear; alternatively, some of them may represent sea-level oscillations within more substantial eustatic cycles.

The Lange Ranch event is one of the most pronounced eustatic minima. It is best recognizable in the Cambrian–Ordovician boundary sequences of Baltia (the Baltic paleobasin), Laurasia, and the Australian part of Gondwana (Popov *et al.*, 1989; Nicoll *et al.*, 1992). In the England–Wales part of the Gondwana margins, the continuous sedimentation occurred only in the periphery of northern Wales. In Shropshire, the Upper Cambrian glauconitic shale (the *Peltura* Zone) is overlain by the Tremadocian deposits with *Rhabdinopora flabelliforme*, and older subspecies of this genus are unknown here (Fortey, 1984). Synchronous regressive events are documented in the Australian part of Gondwana and Siberian Plate. The Lange Ranch event is also well recognizable on the East European (middle latitudes) and North American (the tropical belt) plates.

Data on the Baltic paleobasin show that eustatic oscillations close to the Lange Ranch event were complicated. This event was preceded by a short-term sea-level fall in the Baltic paleobasin at the beginning of the *andresi* Zone. The eustatic nature of these oscillations is confirmed by similar data obtained on the Cambrian–Ordovician boundary sequence in the Lesser Karatau Range (Apollonov *et al.*, 1988; Fig. 2). Despite the changes in the composition of the cold-water trilobite and brachiopod fauna, they do not display substantial variations in the inner structure. Their assemblages retained a poor taxonomic diversity and dominating role of olenids among trilobites and obolid among brachiopods. Nonetheless, perceptible changes in the generic and specific composition of obolids took place due to the immigration of a new poorly diverse fauna, although the previous structure of the assemblage remained unchanged (Popov *et al.*, 1989).

The Lange Ranch event most significantly affected the warm-water biotas. Some trilobite faunas became extinct. In Laurentia (the North American craton), this event corresponds to the end of the ptychapsid biomere, when 95% of the trilobite genera disappeared (Sloan, 1991). A complete renewal of trilobite assemblages is recorded at the same level in sections of southern Kazakhstan (Apollonov, 1991).

The biotic changes mentioned above can partially be explained by the invasion of oxygen-depleted water onto shelves (Erdtmann, 1986). The first appearance of dark-colored carbonates on the North American craton is evident at the level of the *proavus* Zone (= the *apopsis* Zone after Ludwigsen, 1982; Fig. 20). The extensive distribution areas of the olenid biofacies are related to these carbonates as well; the first maximum of the black shale sedimentation in the Baltic paleobasin corresponds approximately to the same time.

After the Lange Ranch event, abrupt changes affected the composition of the warm-water conodont fauna, for instance, paraconodonts were replaced by euconodonts (Dubinina, 1991).

The *Acerocare* and Black Mountain events should be interpreted as pronounced oscillations within a greater eustatic rhythm. Both events are reliably recognized in the north China and Australian parts of Gondwana, and in Baltia. The first appearance of nematophore graptoloids (*Staurograptus* and *Rhabdinopora*) is associated with the transgression that succeeded the *Acerocare* event.

These eustatic events substantially affected the character of sedimentation in sections of the Avalonian microcontinent.

The transgression, which followed the Black Mountain event, was accompanied by a wide development of black shale sedimentation with related "dictyonemid" biofacies on cratons at high and middle latitudes (Baltia, the North African and North American parts of Gondwana, Avalonia). The "dictyonemid" biofacies (*Rhabdinopora* and *Staurograptus*) were widespread in extremely shallow-water environments in the Baltic paleobasin, which is evident from graptolite detritus found in obliquely laminated sandstones among black shales (the Baltic-Ladoga glint). Such taphonomic peculiarities favor the elevated upper level of the oxygen minimum layer. It is possible that at this time, the surface water rich in oxygen was freshened. This resulted, on the one hand, in the substantial increase of biologic productivity in the basin and, on the other hand, in the almost complete extinction of benthos. The *Scolites* ichnofacies disappeared, whereas the benthic fauna was represented exclusively by sponges of the *Protospongia* genus, whose spicules form in places thin spongolite interlayers (Popov *et al.*, 1989).

Sedimentological changes along the periphery of the Baltic paleobasin were insignificant during the greater part of the Tremadocian, as it is evident from a continuous black shale sedimentation here from the beginning of the Late Cambrian. Biotic changes in the region are marked by the appearance of new olenid genera (*Parabolinella*, *Boeckaspis* and *Jujuaspis*), and by development of the specific *Broeggeria* lingulate assemblage (Popov and Holmer, 1994). In the Tremadocian, the geographic range of this assemblage included, in addition to the Baltic plate, a part of Gondwana situated in high and middle latitudes, along with the microcontinents and island arcs bordering its periphery (Avalonia, and south Kazakhstan terranes).

The comparative analysis of the Tremadocian deposits of Laurentia is difficult because of the uncertain zonal correlation based on conodonts. The trilobite fauna presumably experienced no dramatic changes in contrast to those that took place during the Lange Ranch event and in the middle Arenigian (Ludwigsen and Westorp, 1983; Sloan, 1991).

The evolution of the pelagic fauna (conodonts) proceeded in the same way as after the Lange Ranch event. The radiation of euconodonts was still in progress in the warm-water area, and they became dominant in cold-water assemblages as well.

The *Peltocare* event, distinguished in Baltoscandia (Erdtmann, 1986), is also identified in sections of the Australian part of Gondwana (Nicoll *et al.*, 1992). It is not analogous to the Black Mountain event, as Erdtmann expected, but occurred later, at the beginning of the *deltifer* Zone. This interval is less studied as compared to earlier ones, and its global sedimentological and subsequent biotic changes are still not clearly understood. The appearance of the *Ceratopyge* trilobite fauna on the Baltic craton falls on the transgression after the *Peltocare* event. The accumulation of black shales in inner parts of the Baltic paleobasin ceased above the hiatusis synchronous to this event, which indicates a drastic decrease in the primary biologic productivity; concurrently glauconite appears in sediments.

The *Ceratopyge* event (Erdtmann, 1986) is reliably traceable in the Baltoscandian sections by the eustatic minimum at the end of the *deltifer* Zone. The subsequent diachronous transgression commenced at the end of the Tremadocian (the *proteus* Zone). The transgression went on throughout the early Arenigian, and reached its maximum at the time of the *evae* Zone. Sedimentological and biotic changes of this interval are less understood as compared to those of the Lange Ranch and Black Mountain events, whose levels are directly related to the problem of the Cambrian–Ordovician boundary. Nevertheless, the interval in question deserves special attention, as it marks the beginning of the intense Ordovician radiation of planktonic and benthic faunas, as well as the origin of new types of shelf assemblages.

Graptolites are exclusively rare in platform sequences synchronous with the *Ceratopyge* event. The mass extinction of widespread anisograptid colonies, and the appearance of intermediate dendroid–graptoloid fauna (*Araneograptus*, *Clonograptus*) coincide with this event (Erdtmann, 1986). The new dichograptid fauna appears with the onset of the early Arenigian transgression to occupy cratons, and then to spread worldwide. Deep evolutionary changes in graptoloids are expressed in substantial morphological transformations, such as the bitheca loss and the reduction of the number of branches. The radiation and further increase in the taxonomic and morphologic diversity of conodont assemblages are also confined to this interval.

A new and more diverse benthic fauna penetrates into the Baltic paleobasin at the end of the Tremadocian–beginning of the Arenigian. The *Thysanotos* lingulate assemblage occupies the shallow-water biotopes. In the east, it is substituted for *Panderina* and *Ranorthis* articulate brachiopod assemblage. Both assemblages are cryptogenic. The subsequent early Arenigian events of the step-by-step immigration resulted in a wide distribution of a new and very diverse

benthic fauna. Previously unknown bryozoans, ostracods and various groups of echinoderms became widespread along with brachiopods. The above mentioned changes occurred against the background of a further decrease in the primary biologic productivity in the basin, expressed in the cessation of black shale sedimentation over the entire shelf, and in the gradual transition to predominantly carbonate sedimentation at the beginning of the *elegans* Zone. The early Arenigian transgression is reflected in the trilobite fauna by the maximum diversity of bathyurid assemblages in Laurentia, which also spread over the Angarian paleocontinent and the north China part of Gondwana (Cocks and Fortey, 1990). The radiation of asaphids in the Baltic paleobasin is of the same significance (Tjernvik, 1956). The mentioned biotic changes occurred against the background of a sharp decrease in the biologic productivity that terminated the black shale sedimentation on shelves, caused the appearance of glauconite, and initiated carbonate accumulation.

With the advent of the Arenigian transgression, the taxonomic diversity in the conodont and graptolite faunas increased within the cold- and warm-water distribution areas, whose configuration remained unchanged. However, this increase could be related to the intensification of the bathymetric differentiation. Graptolites invaded shelves, where epiplanktonic assemblages were represented by the didymograptid biofacies (*Phyllograptus*, *Didymograptus*, and *Tetragraptus*) characteristic of basin zones with the sufficient oxygen content (green and gray shales, mudstones and limestones). They show a low taxonomic diversity with one or several taxons as dominants, and the confinement to both the high and low latitudes. Only some taxons had limited distribution areas in high and middle latitudes (*Azygograptus*), or showed the relatively cosmopolitan type of distribution in low and some middle latitudes (*Tetragraptus approximatus*). The specific and diverse isograptid biofacies were formed in the course of the Arenigian transgression in the deep-water biotopes on continental margins (Cocks and Fortey, 1990; Cooper *et al.*, 1991). They spanned water areas from tropical to high-temperate latitudes that could be related to the relative stability of water mass characteristics below the thermocline. The isograptid assemblages (*Isograptus*, *Oncograptus*, *Cardiograptus*, *Sigmagraptus*, as well as *Kiaerograptus*, and *Didymograptus protobalticus* from cold-water areas) are usually associated with specific black shale sequences. The global distribution of these graptolites is used as an important criterion for mapping the continental plates of the Arenigian time (Fortey and Cocks, 1986).

DISCUSSION

Some papers published during the last decade assume that transgressive-regressive cycles at the Cambrian–Ordovician boundary could be related to the development and degradation of continental glaciation in the southern hemisphere (Fortey, 1984; Miller, 1984). However, direct evidence of the presence of the ice sheet there are unavailable, except the data on glaciomarine deposits in northern Argentina and southern Bolivia (Erdtmann, 1986).

Nonetheless, the complicated character of eustatic oscillations in the interval between the Lange Ranch and Black Mountain events indicates that glaciation was quite possible. The paleogeographic situation after the *Acerocare* and Black Mountain events is reflected in the transgression and related black shale sedimentation, and resembles that at the Ordovician–Silurian boundary (*Global Analysis* ..., 1988), further, it may well evidence the onset of interglacial (post-*Acerocare*), or postglacial epochs.

The situation at the time of the *Peltocare* and *Ceratopyge* events is discordant with the climatic model described above. Transgressions, which followed these events, were not accompanied by black shale sedimentation on shelves and continental margins, and after the *Ceratopyge* event, the black shale sedimentation also ceased on continental margins. This was caused by several factors, such as the low productivity of phytoplankton, retention of vertical circulation, and absence of distinct stratification in oceanic waters and related layers of the oxygen minimum. In addition, it can be assumed that the surface water temperature in polar areas was still low (less than 5°C), and this water could be the main source for water mass formation in deep oceanic layers. The radiation of fauna, which commenced in the Arenigian, could result from the decrease in the intraspecific competition under conditions of a relatively low primary biologic productivity. At the same time, the oxygenation of shelf waters substantially widened the biotope diversity and resulted in the biologic expansion of the benthic fauna. The immigration of mature cryptogenic assemblages played an important role in this process. The generation rate of faunal diversity is difficult to estimate, though the radiation effect became evident in local phylogenetic lines later, as, for instance, in the Baltic paleobasin.

CONCLUSION

Paleoclimatic reconstructions for the Late Cambrian–Early Ordovician meet some difficulties because of the following factors. As a rule, traces of the last glaciation are best preserved on territories that had relatively stable positions in polar latitudes. Traces of the preceding glaciations were eliminated in most cases by postglacial erosion, and as a result of the subsequent ice sheet expansion. For instance, only the Late Ordovician glaciation is reliably recorded in the North African and South American parts of Gondwana. For detecting earlier glaciations, the search for reliably dated glaciomarine deposits similar to those revealed in Argentina and Bolivia is the most promising.

The *Acerocare* and Black Mountain events should be interpreted as pronounced oscillations within a greater eustatic rhythm. Both events are reliably recognized in the north China and Australian parts of Gondwana, and in Baltia. The first appearance of nematophore graptoloids (*Staurograptus* and *Rhabdinopora*) is associated with the transgression that succeeded the *Acerocare* event.

These eustatic events substantially affected the character of sedimentation in sections of the Avalonian microcontinent.

The transgression, which followed the Black Mountain event, was accompanied by a wide development of black shale sedimentation with related "dictyonemid" biofacies on cratons at high and middle latitudes (Baltia, the North African and North American parts of Gondwana, Avalonia). The "dictyonemid" biofacies (*Rhabdinopora* and *Staurograptus*) were widespread in extremely shallow-water environments in the Baltic paleobasin, which is evident from graptolite detritus found in obliquely laminated sandstones among black shales (the Baltic-Ladoga glint). Such taphonomic peculiarities favor the elevated upper level of the oxygen minimum layer. It is possible that at this time, the surface water rich in oxygen was freshened. This resulted, on the one hand, in the substantial increase of biologic productivity in the basin and, on the other hand, in the almost complete extinction of benthos. The *Scolites* ichnofacies disappeared, whereas the benthic fauna was represented exclusively by sponges of the *Protospongia* genus, whose spicules form in places thin spongolite interlayers (Popov *et al.*, 1989).

Sedimentological changes along the periphery of the Baltic paleobasin were insignificant during the greater part of the Tremadocian, as it is evident from a continuous black shale sedimentation here from the beginning of the Late Cambrian. Biotic changes in the region are marked by the appearance of new olenid genera (*Parabolinella*, *Boeckaspis* and *Jujuaspis*), and by development of the specific *Broeggeria* lingulate assemblage (Popov and Holmer, 1994). In the Tremadocian, the geographic range of this assemblage included, in addition to the Baltic plate, a part of Gondwana situated in high and middle latitudes, along with the microcontinents and island arcs bordering its periphery (Avalonia, and south Kazakhstan terranes).

The comparative analysis of the Tremadocian deposits of Laurentia is difficult because of the uncertain zonal correlation based on conodonts. The trilobite fauna presumably experienced no dramatic changes in contrast to those that took place during the Lange Ranch event and in the middle Arenigian (Ludwigsen and Westorp, 1983; Sloan, 1991).

The evolution of the pelagic fauna (conodonts) proceeded in the same way as after the Lange Ranch event. The radiation of euconodonts was still in progress in the warm-water area, and they became dominant in cold-water assemblages as well.

The *Peltocare* event, distinguished in Baltoscandia (Erdtmann, 1986), is also identified in sections of the Australian part of Gondwana (Nicoll *et al.*, 1992). It is not analogous to the Black Mountain event, as Erdtmann expected, but occurred later, at the beginning of the *deltifer* Zone. This interval is less studied as compared to earlier ones, and its global sedimentological and subsequent biotic changes are still not clearly understood. The appearance of the *Ceratopyge* trilobite fauna on the Baltic craton falls on the transgression after the *Peltocare* event. The accumulation of black shales in inner parts of the Baltic paleobasin ceased above the hiatusis synchronous to this event, which indicates a drastic decrease in the primary biologic productivity; concurrently glauconite appears in sediments.

The *Ceratopyge* event (Erdtmann, 1986) is reliably traceable in the Baltoscandian sections by the eustatic minimum at the end of the *deltifer* Zone. The subsequent diachronous transgression commenced at the end of the Tremadocian (the *proteus* Zone). The transgression went on throughout the early Arenigian, and reached its maximum at the time of the *evae* Zone. Sedimentological and biotic changes of this interval are less understood as compared to those of the Lange Ranch and Black Mountain events, whose levels are directly related to the problem of the Cambrian–Ordovician boundary. Nevertheless, the interval in question deserves special attention, as it marks the beginning of the intense Ordovician radiation of planktonic and benthic faunas, as well as the origin of new types of shelf assemblages.

Graptolites are exclusively rare in platform sequences synchronous with the *Ceratopyge* event. The mass extinction of widespread anisograptid colonies, and the appearance of intermediate dendroid–graptoloid fauna (*Araneograptus*, *Clonograptus*) coincide with this event (Erdtmann, 1986). The new dichograptid fauna appears with the onset of the early Arenigian transgression to occupy cratons, and then to spread worldwide. Deep evolutionary changes in graptoloids are expressed in substantial morphological transformations, such as the bitheca loss and the reduction of the number of branches. The radiation and further increase in the taxonomic and morphologic diversity of conodont assemblages are also confined to this interval.

A new and more diverse benthic fauna penetrates into the Baltic paleobasin at the end of the Tremadocian–beginning of the Arenigian. The *Thysanotos* lingulate assemblage occupies the shallow-water biotopes. In the east, it is substituted for *Panderina* and *Ranorthis* articulate brachiopod assemblage. Both assemblages are cryptogenic. The subsequent early Arenigian events of the step-by-step immigration resulted in a wide distribution of a new and very diverse

benthic fauna. Previously unknown bryozoans, ostracods and various groups of echinoderms became widespread along with brachiopods. The above mentioned changes occurred against the background of a further decrease in the primary biologic productivity in the basin, expressed in the cessation of black shale sedimentation over the entire shelf, and in the gradual transition to predominantly carbonate sedimentation at the beginning of the *elegans* Zone. The early Arenigian transgression is reflected in the trilobite fauna by the maximum diversity of bathyurid assemblages in Laurentia, which also spread over the Angarian paleocontinent and the north China part of Gondwana (Cocks and Fortey, 1990). The radiation of asaphids in the Baltic paleobasin is of the same significance (Tjernvik, 1956). The mentioned biotic changes occurred against the background of a sharp decrease in the biologic productivity that terminated the black shale sedimentation on shelves, caused the appearance of glauconite, and initiated carbonate accumulation.

With the advent of the Arenigian transgression, the taxonomic diversity in the conodont and graptolite faunas increased within the cold- and warm-water distribution areas, whose configuration remained unchanged. However, this increase could be related to the intensification of the bathymetric differentiation. Graptolites invaded shelves, where epiplanktonic assemblages were represented by the didymograptid biofacies (*Phyllograptus*, *Didymograptus*, and *Tetragraptus*) characteristic of basin zones with the sufficient oxygen content (green and gray shales, mudstones and limestones). They show a low taxonomic diversity with one or several taxons as dominants, and the confinement to both the high and low latitudes. Only some taxons had limited distribution areas in high and middle latitudes (*Azygograptus*), or showed the relatively cosmopolitan type of distribution in low and some middle latitudes (*Tetragraptus approximatus*). The specific and diverse isograptid biofacies were formed in the course of the Arenigian transgression in the deep-water biotopes on continental margins (Cocks and Fortey, 1990; Cooper *et al.*, 1991). They spanned water areas from tropical to high-temperate latitudes that could be related to the relative stability of water mass characteristics below the thermocline. The isograptid assemblages (*Isograptus*, *Oncograptus*, *Cardiograptus*, *Sigmagraptus*, as well as *Kiaerograptus*, and *Didymograptus protobalticus* from cold-water areas) are usually associated with specific black shale sequences. The global distribution of these graptolites is used as an important criterion for mapping the continental plates of the Arenigian time (Fortey and Cocks, 1986).

DISCUSSION

Some papers published during the last decade assume that transgressive-regressive cycles at the Cambrian–Ordovician boundary could be related to the development and degradation of continental glaciation in the southern hemisphere (Fortey, 1984; Miller, 1984). However, direct evidence of the presence of the ice sheet there are unavailable, except the data on glaciomarine deposits in northern Argentina and southern Bolivia (Erdtmann, 1986).

Nonetheless, the complicated character of eustatic oscillations in the interval between the Lange Ranch and Black Mountain events indicates that glaciation was quite possible. The paleogeographic situation after the *Acerocare* and Black Mountain events is reflected in the transgression and related black shale sedimentation, and resembles that at the Ordovician–Silurian boundary (*Global Analysis* ..., 1988), further, it may well evidence the onset of interglacial (post-*Acerocare*), or postglacial epochs.

The situation at the time of the *Peltocare* and *Ceratopyge* events is discordant with the climatic model described above. Transgressions, which followed these events, were not accompanied by black shale sedimentation on shelves and continental margins, and after the *Ceratopyge* event, the black shale sedimentation also ceased on continental margins. This was caused by several factors, such as the low productivity of phytoplankton, retention of vertical circulation, and absence of distinct stratification in oceanic waters and related layers of the oxygen minimum. In addition, it can be assumed that the surface water temperature in polar areas was still low (less than 5°C), and this water could be the main source for water mass formation in deep oceanic layers. The radiation of fauna, which commenced in the Arenigian, could result from the decrease in the intraspecific competition under conditions of a relatively low primary biologic productivity. At the same time, the oxygenation of shelf waters substantially widened the biotope diversity and resulted in the biologic expansion of the benthic fauna. The immigration of mature cryptogenic assemblages played an important role in this process. The generation rate of faunal diversity is difficult to estimate, though the radiation effect became evident in local phylogenetic lines later, as, for instance, in the Baltic paleobasin.

CONCLUSION

Paleoclimatic reconstructions for the Late Cambrian–Early Ordovician meet some difficulties because of the following factors. As a rule, traces of the last glaciation are best preserved on territories that had relatively stable positions in polar latitudes. Traces of the preceding glaciations were eliminated in most cases by postglacial erosion, and as a result of the subsequent ice sheet expansion. For instance, only the Late Ordovician glaciation is reliably recorded in the North African and South American parts of Gondwana. For detecting earlier glaciations, the search for reliably dated glaciomarine deposits similar to those revealed in Argentina and Bolivia is the most promising.

The experience in studying the Cenozoic glaciation suggests that the most important stages in the evolution and degradation of ice sheets directly affect the vertical circulation and temperature gradient of ocean water. All these changes are best recorded in the Cenozoic oceanic sediments, which serve as the basic material for paleoclimatic reconstructions. For the Ordovician, sediments of shelves and continental margins are sources for such information. Oceanic biogenic sediments are represented solely by radiolarites, which are preserved only in allochthonous oceanic complexes.

Ordovician radiolarites are widely distributed. They are found in the Appalachians, southern Scotland, the Urals and Kazakhstan, and their conodont fauna allows a detailed subdivision and correlation (Koren' *et al.*, 1993). The recent palinspastic reconstructions make it possible to speculate on areas in the World Ocean populated by conodonts. Information on changes in the biologic productivity, degree of oxygenation, stratification, and relative value of the temperature gradient (the availability or the lack of the thermocline) inferable from the Ordovician biogenic sediments has great potential for future paleoclimatic reconstructions.

Reviewers S.V. Dubinina and A.Yu. Rozanov

REFERENCES

A Global Analysis of the Ordovician–Silurian Boundary, Cocks, L.R.M. and Rickards, R.B., Eds., *Bull. Br. Mus. (Nat. Hist.), Geol. Ser.*, 1988, vol. 43.

Apollonov, M.K., Cambrian–Ordovician Boundary Beds in the USSR, in *Advances in Ordovician Geology, Geol. Surv. Can.*, 1991, no. 909-9, pp. 33–45.

Apollonov, M.K., Chugaeva, M.N., Dubinina, S.V., and Zhemchuzhnikov, V.G., Potential Stratotype for the Cambrian–Ordovician Boundary, *Geol. Mag.*, 1988, vol. 125, no. 4, pp. 451–455.

Cocks, L.R.M. and Fortey, R.A., Biogeography of Ordovician and Silurian Faunas, in *Palaeozoic Palaeogeography and Biogeography, Geol. Soc. Mem.*, 1990, no. 12, pp. 97–104.

Cooper, R.A., Fortey, R.A., and Lindholm, K., Latitudinal and Depth Zonation of Early Ordovician Graptolites, *Lethaia*, 1991, vol. 24, pp. 199–219.

Dubinina, S.V., Upper Cambrian and Lower Ordovician Conodont Associations from Open Ocean Paleoenvironments, Illustrated by Batyrbay and Sarykum Sections in Kazakhstan, *Advances in Ordovician Geology*, Pap. Geol. Surv. Can., 1991, no. 90-9, pp. 107–124.

Erdtmann, B.-D., Palaeobiography and Environments of Planctic Dyctyonemid Graptolites during the Earliest Ordovician, in *The Cambrian–Ordovician Boundary Sections, Fossil Distributions and Correlations*, Nat. Mus. Wales, Geol. Ser., 1982, no. 3, pp. 9–27.

Erdtmann, B.-D., Early Ordovician Eustatic Cycles and Their Bearing on Punctuations in Early Nematophorid (Planctic) Graptolite Evolution, *Lecture Notes in Earth Sciences*, vol. 8: *Global Bio-Events*, Berlin: Springer, 1986, pp. 139–152.

Erdtmann, B.-D., The Earliest Ordovician Nematophorid Graptolites: Taxonomy and Correlation, *Geol. Mag.*, 1988, vol. 125, no. 4, pp. 327–348.

Fortey, R.A., Global Early Ordovician Transgressions and Regressions and Their Biological Implications, *Paleontol. Contrib. Univ. Oslo*, 1984, no. 295, pp. 37–50.

Fortey, R.A. and Cocks, L.R.M., Marginal Faunal Belts and Their Structural Implications, with Examples from the Lower Palaeozoic, *J. Geol. Soc. London*, 1986, vol. 143, pp. 151–160.

Koren', T.N., Lytochkin, V.N., Popov, L.E., and Tolmacheva, T.Yu., *Biostratigraficheskii analiz pelagicheskikh strukturno-veshchestvennykh kompleksov paleozoya dlya tselei GSR-50 and GSR-200. Metodicheskie rekomendatsii* (Biostratigraphic Analysis of Pelagic Structural-Lithological Complexes of the Paleozoic for GSR-50 and GSR-200. Methodical Recommendations), St. Petersburg: Vses. Geol. Inst, 1993.

Ludvigsen, R., The Cambrian–Ordovician Boundary in the Western District of Mackenzie, Canada, in *The Cambrian–Ordovician Boundary: Sections, Fossil Distributions and Correlations, Nat. Mus. Wales, Geol. Ser.*, 1982, no. 3, pp. 141–153.

Ludwigsen, R. and Westorp, R.W., Trilobite Biofacies of the Cambrian–Ordovician Boundary Interval in Northern North America, *Alcheringa*, 1983, vol. 7, pp. 301–319.

Martinsson, A., The Cambrian of Norden, in *Lower Paleozoic Rocks of the World*, vol. 2: *Cambrian of the British Isles, Norden und Spitsbergen*, London: Wiley, 1974, pp. 185–283.

Miller, J.F., Cambrian and Earliest Ordovician Conodont Evolution, Biofacies, and Provincialism, *Spec. Pap. Geol. Soc. Am.*, 1984, vol. 196, pp. 43–68.

Miller, J.F., Conodonts as Biostratigraphic Tools for Redefinition and Correlation of the Cambrian–Ordovician Boundary, *Geol. Mag.*, 1988, vol. 125, no. 4, pp. 349–362.

Miller, J.F., The Lange Ranch Eustatic Event: A Regressive–Transgressive Couplet near the Base of the Ordovician System, in *Global Perspectives on Ordovician Geology*, Rotterdam: Balkema, 1992, pp. 395–407.

Nicoll, R.S., Laurie, J.R., Shergold, J.H., and Nielsen, A.T., Preliminary Correlation of Latest Cambrian to Early Ordovician Sea-Level Events in Australia and Scandinavia, in *Global Perspectives on Ordovician Geology*, Rotterdam: Balkema, 1992, pp. 381–382.

Popov, L.E. and Holmer, L., Cambrian–Ordovician Stratigraphy and Lingulate Brachiopods from Scandinavia, Kazakhstan, South Ural Mountains, *Fossils and Strata* (Oslo), 1984, vol. 35.

Popov, L.E., Khazanovich, K.K., Borovko, N.G., Sergeeva, S.P., and Sobolevskaya, R.F., Reference Sections and Stratigraphy of the Cambrian–Ordovician Phosphate-bearing *Obolus* Beds on the Northwestern Russian Platform, *Tr. Mezhved. Stratigr. Komis. SSSR*, 1989, vol. 18.

Scotese, C.R. and McKerrow, W.C., Ordovician Plate Tectonic Reconstructions, in *Advances in Ordovician Geology, Pap. Geol Sur. Can.*, 1991, no. 90-9, pp. 283–298.

Sengor, A.M.C., Natal'in, B.A., and Burtman, V.S., Evolution of the Altaid Tectonic Collage and Palaeozoic Crustal Growth in Eurasia, *Nature*, 1993, vol. 364, pp. 299–307.

Shergold, J., Review of Trilobite Biofacies Distribution at the Cambrian–Ordovician Boundary, *Geol. Mag.*, 1988, vol. 125, no. 4, pp. 381–414.

Sloan, R.E., A Chronology of the North American Ordovician Trilobite Genera, in *Advances in Ordovician Geology, Pap. Geol. Surv. Can.*, 1991, no. 90-9, pp. 165–178.

Tjernvik, T.E., On the Early Ordovician of Sweden. Startigraphy and Fauna, *Bull. Geol. Inst., Univ. Upsala*, 1956, vol. 36, pp. 107–284.

Trench, A. and Tornsvik, T.H., The Closure of the Japetus Ocean and Tornquist Sea: New Paleomagnetic Constraints, *J. Geol. Soc. London*, 1992, vol. 149, part 6, pp. 867–870.

Whittington, H.B. and Hughes, C.P., Ordovician Geography and Faunal Provinces Deduced from Trilobite Distribution, *Philos. Trans. R. Soc. London, Ser. B*, 1974, vol. 263, pp. 235–278.

Wilde, P., Oceanography in the Ordovician, in *Advances in Ordovician Geology, Pap. Geol. Surv. Can.*, 1991, no. 90-9, pp. 283–298.

Williams, A., Distribution of Brachiopod Assemblages in Relation to Ordovician Palaeogeography, in *Organisms and Continents through Time, Spec. Pap. Paleontol.*, 1973, vol. 12, pp. 241–269.

Yarusnoe raschlenenie nizhnego kembriya. Stratigrafiya (Stage Subdivisions of the Lower Cambrian. Stratigraphy), Rozanov, A.Yu. and Sokolov, B.S., Eds., Moscow: Nauka, 1984.

Stratigraphy and Geological Correlation, Vol. 4, No. 5, 1996, pp. 428–439. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 5, 1996, pp. 13–24.
Original Russian Text Copyright © 1996 by Barskov, Reimers.
English Translation Copyright © 1996 by МАИК Наука/Interperiodica Publishing (Russia).

Carboniferous-Permian Boundary as Indicated by Conodonts

I. S. Barskov and A. N. Reimers

Moscow State University, Vorob'evy gory, Moscow, 119899 Russia

Received October 25, 1994; in final form, January 16, 1995

Abstract—The analysis of successive conodont assemblages from Carboniferous-Permian boundary sediments of the Aidarlash and Usolka sections revealed that the boundary approaching that in the ammonoid standard is in the transition interval between the following species: *Streptognathodus alius* ⇒ *barskovi*; *Str. simplex* ⇒ *asselicus*; *Str. elongatus* ⇒ *cristellaris*; *Str. elongatus* ⇒ *minacutus*. Two key species *Str. barskovi* and *Str. minacutus* sp. nov. = *Str. acuminatus* Gunnell sensu Chernikh were redescribed. The phylogenetic relationships between *Streptognathodus* species in the designated interval were traced.

Key words: *Carboniferous, Permian, conodonts, boundary, phylogenetic relationships, Aidarlash, Usolka.*

INTRODUCTION

The Carboniferous-Permian boundary was first defined according to the appearance of the Asselian ammonoid assemblage, which includes genera *Svetlanoceras*, *Juresanites*, *Protopopanoceras*, *Properrinites*, and *Prostacheoceras* (Bogoslovskaya *et al.*, 1991; Davydov *et al.*, 1991).

Beyond the ammonoid facies, the boundary was customarily placed at the base of the lower Asselian fusulinid *Sphaeroschwagerina vulgaris–S. fusiformis* (s.l.) Zone. The recent refinement of the zonal subdivision of boundary sediments according to fusulinids, and correlation of fusulinid zones with ammonoid assemblages showed that the Asselian ammonoid assemblage appeared in the upper part of the *S. vulgaris–S. fusiformis* Zone. The lower part of this zone was distinguished as a separate *Daixina robusta–D. bosbytauensis* Zone (*Postanovlenie* ..., 1985).

Conodont zonations for the Carboniferous-Permian boundary sediments

Movshovich *et al.*, 1979	Barskov, 1984	Isakova and Nazarov, 1986	Chernykh and Reshetkova, 1987	Chuvashov, 1990	Akhmetshina, 1990	Fusulinid zones
G. bisselli *S. simplex* *I. delicatus*	*N. bisselli*		*N. bisselli* *S. postfusus*	*N. bisselli*	*N. bisselli*	*Pseudofusulina moelleri*
S. barskovi	*S. barskovi*	Assemblage with *S. barskovi*		*S. postfusus*	*S. postfusus*	*S. sphaerica* *P. firma*
S. elongatus *S. wabaunsensis*			*S. constrictus* *S. fusus*	*S. fusus* *S. constrictus*	*S. constrictus*	*S. moelleri* *P. fecunda*
S. simplex *S. elongatus* *S. wabaunsensis*	*S. wabaunsensis*	Assemblage with *S. wabaunsensis*	*S. cristellaris*	*S. cristellaris* *S. wabaunsensis*	*S. cristellaris*	*S. vulgaris* *S. fusuformis*
			S. wabaunsensis	*S. elongatus*	*S. alius* *S. wabaunsensis*	*D. robusta* *D. bosbytauensis*
S. elongatus *S. simplex* *S. ruzhencevi* *S. elengantulus*	*S. elongatus*	Assemblage with *S. elegantulus* *S. elongtus*	*S. elongatus*	*S. elongatus*	*S. elongatus*	*D. sokensis*

Note: —— Carboniferous-Permian boundary; — zonal boundaries; – – – suggested zonal boundaries.

At the same time, the role of conodonts in the subdivision of Upper Carboniferous and Lower Permian sediments increased. Their correlation potential appeared to be rather high. Several conodonts zonations for boundary sediments were proposed (table). The position of the boundary in these zonations substantially varied due to the different precision of dating the studied sections with respect to fusulinid and ammonoid schemes, and owing to the authors' opinion. Some authors held to the idea of its position at the base of the *S. vulgaris–S. fusiformis* (s. l.) Zone (that is, at the base of the *D. robusta–D. bosbytauensis* Zone), while others place it at the base of the *S. vulgaris–S. fusiformis* (s. str.) Zone. Proposals were also made to place the boundary at the base of the middle Asselian *S. moelleri–P. fecunda* Zone, or at the base of the Sakmarian. However, this latter viewpoint was not supported, as it did not fit the priority principle. Therefore, the Interdepartmental Stratigraphic Committee accepted and approved the boundary position corresponding to the ammonoid standard (*Postanovlenie* ..., 1985).

Despite the differences in zonations, the investigation of conodonts revealed the reliably defined stratigraphic succession of *Streptognathodus* species. The degree of conodont examination makes it possible to refine the key species distribution in the boundary interval and raise the question regarding the biostratigraphic definition of the Carboniferous-Permian boundary based on conodonts in compliance with the ammonoid standard.

This paper analyzes the succession of conodont assemblages from the Aidarlash and Usolka reference sections in the Southern Urals according to published data (Akhmetshina *et al.*, 1984; Barskov, 1991; Barskov *et al.*, 1981; Barskov and Reimers, 1992; Isakova and Nazarov, 1986; Reshetkova and Chernykh, 1986; Chernykh and Reshetkova, 1987, 1988; Chernykh and Chuvashov, 1991) along with our new material. We suggest new taxonomic concepts for the two key species, which are ambiguously understood, and trace the phylogenetic lineage of *Streptognathodus* species distributed in the boundary interval.

This work is an outgrowth of previous preliminary investigations outlined in a deposition and paper presented at the International Congress *Permian System of the Earth* in August, 1991 (Davydov *et al.*, 1991).

TAXONOMIC REMARKS

The biostratigraphic determination of the Carboniferous-Permian boundary above all requires agreeable taxonomic comprehension of key species distributed close to the boundary, and the elucidation of their phylogenetic succession.

Based on personal communications and scientific meetings held in recent years, Russian paleontologists attained a more or less unique comprehension of many boundary species, especially those that were originally described from Russia and Kazakhstan, namely, the Caspian syneclise. Nevertheless, there are some difficulties in identifying certain species first described from North American sections by Gunnell (1933) and later revised by Ellison (1941) and, partly, by Ritter (1991). Consultations on conodonts during the International Congress on the Permian System showed that disagreements on taxonomic concepts, synonymy, and recognition of some species still remain.

Our understanding of the taxonomic position of two species is as follows:

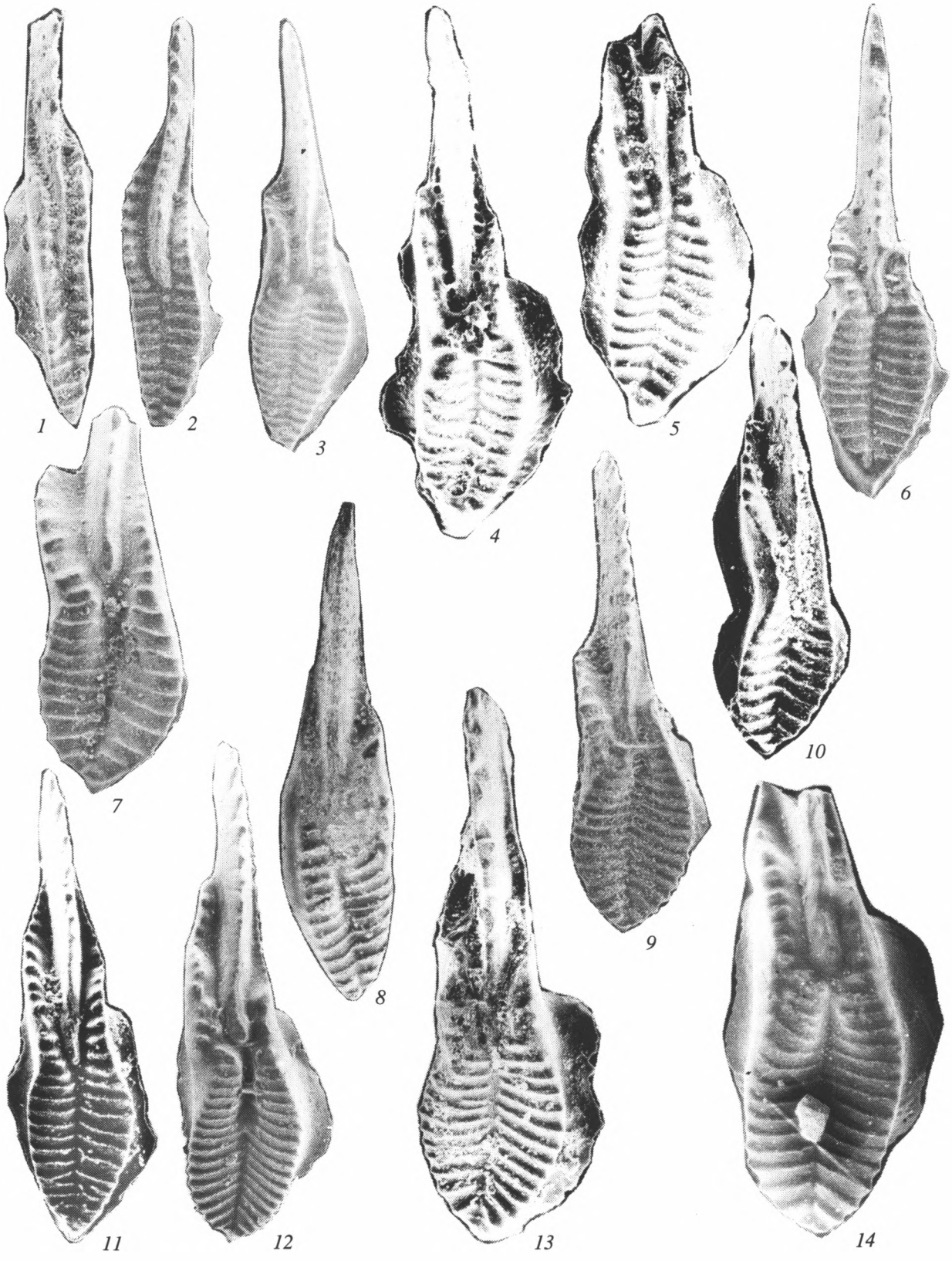
(1) Streptognathodus acuminatus Gunnell, 1933

The species was described in 1933, when the type species was collected from the Americus limestone, Locality 3 in Kansas (Gunnell, 1933). Ellison (1941) placed this species together with three others in synonymy with *Streptognathodus wabaunsensis* Gunnell. Chernykh (Chernykh and Reshetkova, 1987), who studied the Uralian materials, disagreed with Ellison's synonymy and identified *Str. acuminatus* displaying substantial distinctions from *Str. wabaunsensis*. The major diagnostic feature of *Str. acuminatus* is the interrupted anterior branch of the inner parapet, whereas the latter species has in this place a series of isolated nodes, which form an accessory lobe indistinctly separated from the platform. These features discriminate adult specimens, whereas young forms almost cannot be referred to one or another species.

As Ritter showed at the conodont symposium in Perm, holotypes of the above-mentioned species were represented by small young specimens. It is impossible to reveal the differences between them in such a way as Chernykh did. Therefore, the acceptance of *Str. wabaunsensis* Gunnell and *Str. acuminatus* Gunnell as synonyms, as Ellison suggested, appears to be the most adequate idea. In any case, to deny this synonymy, one should provide data which cannot be obtained from the study on the type material. In this situation, the species, which is identified in the Uralian materials as *Str. acuminatus* Gunnell, according to Chernykh's concept accepted by Russian researchers must get another taxonomic name. Below we cite its redescription under the new name *Str. minacutus* sp. nov.

(2) Streptognathodus barskovi Kozur, 1976

There is a sufficiently complicated situation with regard to the comprehension and recognition of the Early Permian species *Str. barskovi*. Originally described from the upper fusulinid zone of the Asselian in the Tabantal section (Kozur and Mostler, 1976), this species was soon found in older deposits (Akhmetshina *et al.*, 1984; Chernykh and Reshetkova, 1987, 1988). The species concept was therewith based not on the topotype material, but on subsequent findings from other localities. The broad platform, substantially


1
2
3
4
5
6
7
8
9
10
11
12
13
14

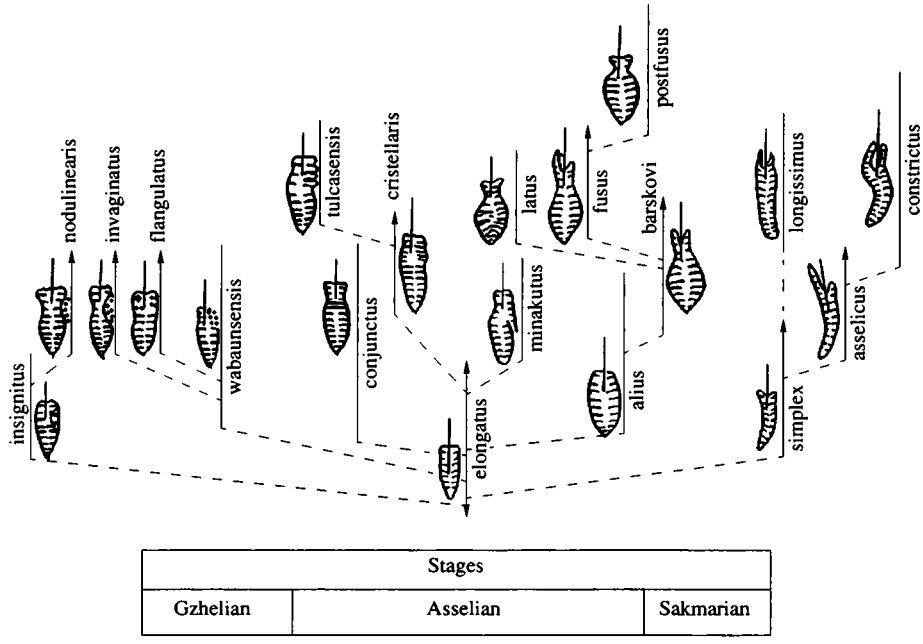


Fig. 1. Phylogeny of Early Permian conodonts of the *Streptognathodus* genus.

broader than among all forms known at that time, was the single diagnostic feature of the species.

However, it turned out that forms with a broad platform occurred considerably lower than the Asselian middle zone, even in the Carboniferous sediments. Due to a large stratigraphic gap with type species, Carboniferous forms with a broad platform were distinguished as a separate species *Str. alius* Akhmetshina (Akhmetshina, 1990). In other cases, broad-platform forms from sediments older than those of the middle zone were identified as *Str.* aff. *Str. barskovi*, or *Str.* cf. *Str. barskovi* (Chernykh and Reshetkova, 1987). Unfortunately, according to information of the species' author (the letter dated February 15, 1990; oral communication, 1992), the type material is unavailable for reexamination. M.F. Bogoslovskaya from the Paleontologic Institute, Moscow, kindly provided us with samples of those rocks, which were studied by H. Kozur for distinguishing conodonts in 1975. Thus, we received the topotype material with abundant *Str. barskovi.* Some specimens of this species are presented herein (Plate I, figs. *4*, *5*, *10*, *11*, *13*). In Kozur's opinion, the specimen no. 459 from this material (Plate I, fig. *11*) is the closest to the holotype. Other figured specimens, according to Kozur, also represent the same species. Based on this fact and on materials from other localities, we must modify somewhat the original diagnosis of this form.

The most characteristic diagnostic feature of the species is a combination of the broad platform with long anterior branches of the parapet, constituting more

Plate I. Conodonts of the *Streptognathodus* genus characteristic of the Carboniferous-Permian boundary interval.

(*1*) *Streptognathodus longissimus* Chernikh et Reshetkova: specim. no. 262/18 (×100), samp. 15/1, Usolka River, Southern Urals, Asselian.

(*2*) *Streptognathodus constrictus* Chernikh et Reshetkova: specim. no. 262/82 (×100), samp. 119, Burlinsk 23 Well, Asselian.

(*3–5* and *10–14*) *Streptognathodus barskovi* (Kozur):

(*3*) specim. no. 262/66 (×60), samp. 9-21/2, Aidarlash River, Southern Urals, Lower Permian, Asselian; (*4*) specim. no. 262/458, samp. 591, Tabantal River, Southern Urals, Lower Permian, Asselian; (*5*) specim. no. 262/461, same samp.; (*10*) specim. no. 262/462, same samp.;

(*11*) specim. no. 262/459, same samp.; (*12*) specim. no. 262/71 (×80), samp. 106, Burlinsk 23 Well, Lower Permian, Asselian;

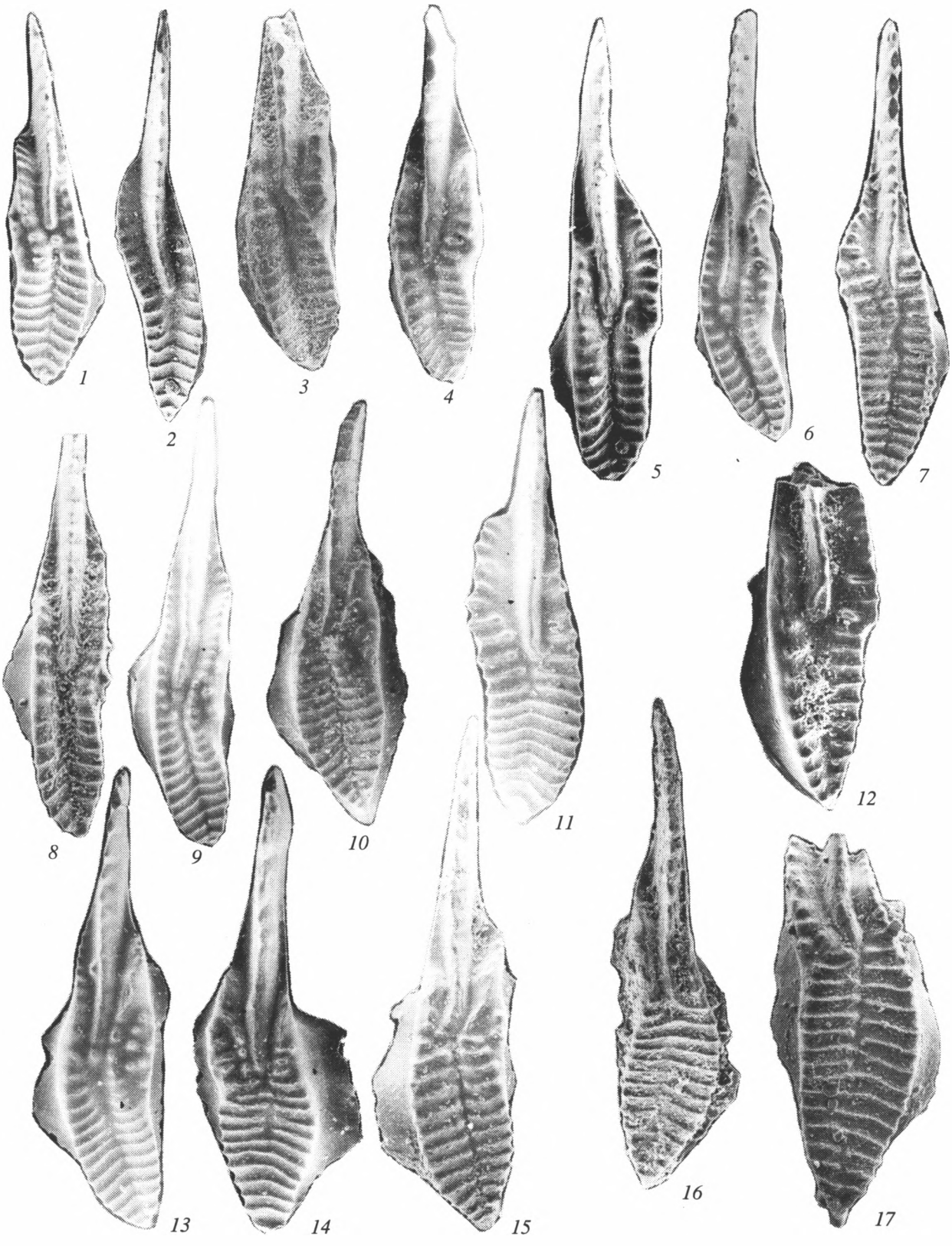
(*13*) specim. no. 262/467, samp. 591, Tabantal River, Southern Urals, Asselian; (*14*) specim. no. 262/72 (×100), samp. 9-21/3, Aidarlash River, Lower Permian, Asselian.

(*6*) *Streptognathodus postfusus* Chernikh et Reshetkova: specim. no. 262/109 (×80), samp. 118, Burlinsk 23 Well, Caspian syneclise, Lower Permian, Asselian.

(*7* and *9*) *Streptognathodus alius* Akhmetshina:

(*7*) specim. no. 262/74 (×100), samp. 106, Burlinsk 23 Well, Caspian syneclise, Lower Permian, Asselian; (*9*) specim. no. 262/69 (×75), samp. 16/2, Usolka River, Lower Permian, Asselian.

(*8*) *Streptognathodus wabaunsensis* Gunnell: specim. no. 262/51 (×80), samp. 9-21/2, Aidarlash River, Southern Urals, Asselian.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

than one-half the length of the platform. This is the difference between *Str. barskovi* and *Str. alius*, which has short branches of parapets.

Phylogeny of the Genus Streptognathodus Stauffer et Plummer, 1932

Major trends in morphologic changes of the conodont genus *Streptognathodus* from the Carboniferous-Permian boundary interval were discussed in recent years by Chernykh (1987, 1988).

Str. elongatus Gunnell, 1933 appeared in the late Gzhelian and was an initial species in the Early Permian radiation of the genus. It has a simple morphology of the platform with a short carina and asymmetric median trough. According to present views, *Str. elongatus* is a descendant of *Str. elegantulus* Stauffer et Plummer, 1932, characterized by symmetric parapets of the platform and carina extending in the form of nodes to the posterior platform margin. The major morphologic change that resulted in the generation of *Str. elongatus* was the junction of the outer parapet ribs with the carina nodes, which led to the formation of an asymmetric furrow and the carina shortening. At the end of the Gzhelian, narrow- and broad-platform varieties of *Str. elongatus* gave rise to species *Str. simplex* Gunnell, 1933, and *Str. alius* Akhmetshina, 1990, respectively. During the Asselian, these species evolved similarly, gradually following the morphologic tendency that previously did not occur in the *Streptognathodus* evolution. Anterior tips of their parapets elongated parallel to a free blade with the formation of long troughs and lapels, or so-called "collars."

The major evolutionary trend of the proper *Str. elongatus* was the morphologic complication of an oral surface of a platform due to the formation of accessory lobes. This morphologic trend took place repeatedly in the previous evolution of the *Streptognathodus* genus. Lobes were formed in different ways. Almost all these morphologic changes were realized anew during a short time span at the end of the Carboniferous and beginning of the Permian on the basis of the initial morphology of *Str. elongatus* (Fig. 1).

Phylogenetic development of broad-platform species from the *elongatus–alius–barskovi–fusus–postfusus* group. *Str. alius* Akhmetshina, 1990 (Plate I, figs. *7* and *9*) originated at the end of the Gzhelian from the broad-platform variety of *Str. elongatus*, and had an enlarged platform with short branches of the parapet. First described from the middle fusulinid zone of the Asselian (Kozur and Mostler, 1976), *Streptognathodus barskovi* (Kozur, 1976) also had a broad platform as *Str. alius*. The major difference between the two species is in the longer anterior branches of the parapet of *Str. barskovi* (Plate I, figs. *3–5* and *10–14*). The branches extend parallel to a free blade for more than one-half the length of the platform. The further lengthening of anterior branches and formation of wide lapels at the junction with the main platform is characteristic of *Str. fusus* Chernikh et Reshetkova, 1987 (Plate II, fig. *17*). The width of its lapels reaches that of the platform, so that the platform has a notable notch. *Str. postfusus* Chernikh et Reshetkova, 1988 (Plate I, fig. *6*) showing the reduction of anterior branches of the parapet, which lose a regular ribbing, and can be considered as a terminal member in this lineage. Its sculpture is represented by irregular inflated nodes and ribs. We regard *Str. latus* as a lateral branch in this lineage. It deviated from *Str. barskovi* at a relatively early stage of the elongation of anterior ends of the parapet. The stage is remarkable because of flattening of an oral surface of a platform, as well as by the ribbing disturbance at a posterior platform margin with the formation of dichotomic thin ribs.

Phylogenetic development of narrow-platform species from the *simplex–asselicus–constrictus–longissimus* group. *Str. simplex* Gunnell, 1933, appeared in the upper Gzhelian as a narrow-platform variety of *Str. elongatus*, and was completely formed in

Plate II. Conodonts of the *Streptognathodus* genus from Carboniferous-Permian boundary sediments.

(*1*, *6*, *8*, *9*) *Streptognathodus nodulinearis* Chernikh et Reshetkova:
(*1*) specim. no. 262/40 (×80), samp. 9-21/3, Aidarlash River, Southern Urals, Asselian; (*6*) specim. no. 262/14 (×75), samp. 9-21/3, Aidarlash River, Southern Urals, Asselian; (*8*) specim. no. 262/17 (×100), samp. 16/2, Usolka River, Southern Urals, Asselian; (*9*) specim. no. 262/15 (×80), samp. 9-21/3, Aidarlash River, Southern Urals, Asselian.
(*2*) *Streptognathodus constrictus* Chernikh et Reshetkova: specim. no. 262/86 (×100), samp. 106, Burlinsk 23 Well, Asselian. (*3*, *5*, *12*) *Streptognathodus minacutus* Barskov et Reimers sp. nov.
(*3*) holotype, specim. no. 262/28 (×100), samp. 16/1, Usolka River, Southern Urals, Asselian; (*5*) specim. no. 262/29 (×80), samp. 106, Burlinsk 23 Well, Caspian syneclise, Asselian; (*12*) specim. no. 262/80 (×100), samp. 16/1, Southern Urals, Usolka River, Lower Permian, Asselian.
(*4*, *7*, *11*) *Streptognathodus cristellaris* Chernikh et Reshetkova:
(*4*) specim. no. 262/91 (×80), samp. 9-21/2, Southern Urals, Aidarlash River, Lower Permian, Asselian; (*7*) specim. no. 262/103 (×80), samp. 16/1, Usolka River, Southern Urals, Lower Permian, Asselian; (*11*) specim. no. 262/104 (×100), same samp. and locality.
(*10*, *13*) *Streptognathodus invaginatus* Chernikh et Reshetkova:
(*10*) specim. no. 262/7 (×80), samp. 9-21/2, Aidarlash River, Southern Urals, Lower Permian, Asselian; (*13*) specim. no. 262/4 (×80), same samp. (*14*, *15*) *Streptognathodus flangulatus* Gunnell:
(*14*) specim. no. 262/23 (×80), samp. 16/1, Usolka River, Southern Urals, Asselian; (*15*) specim. no. 262/24 (×80), samp. 9-21/2, Aidarlash River, Southern Urals.
(*16*) *Streptognathodus conjunctus* Barskov *et al.*: specim. no. 262/46 (×100), samp. 51, Kuznetsov 59 Well, Asselian.
(*17*) *Streptognathodus fusus* Chernikh et Reshetkova: specim. no. 262/111 (×100), samp. 114, Burlinsk 23 Well, Asselian.

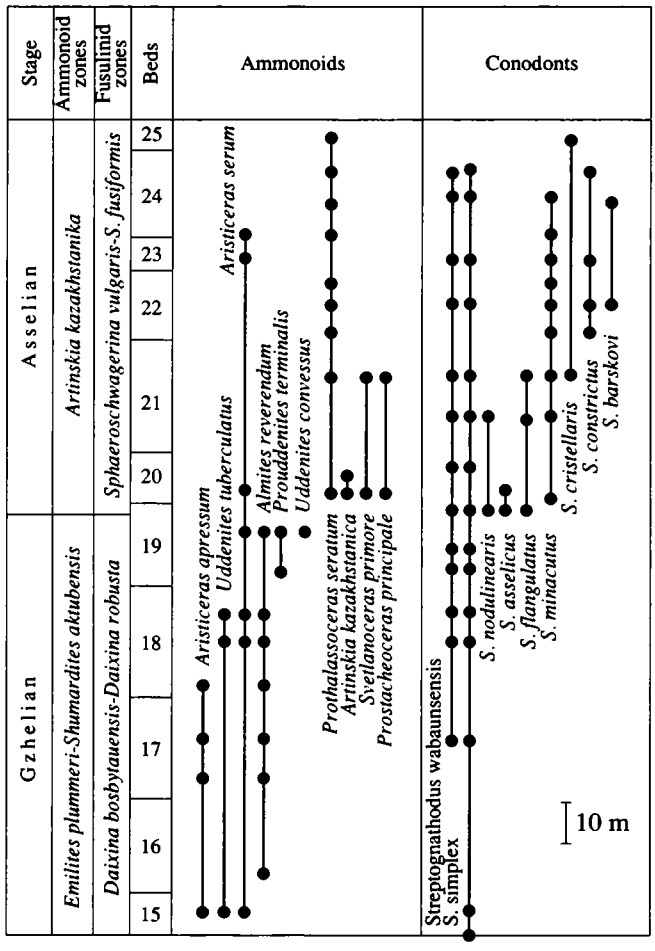


Fig. 2. Distribution of ammonoids and conodonts in the Aidarlash section (after Davydov *et al.*, 1990).

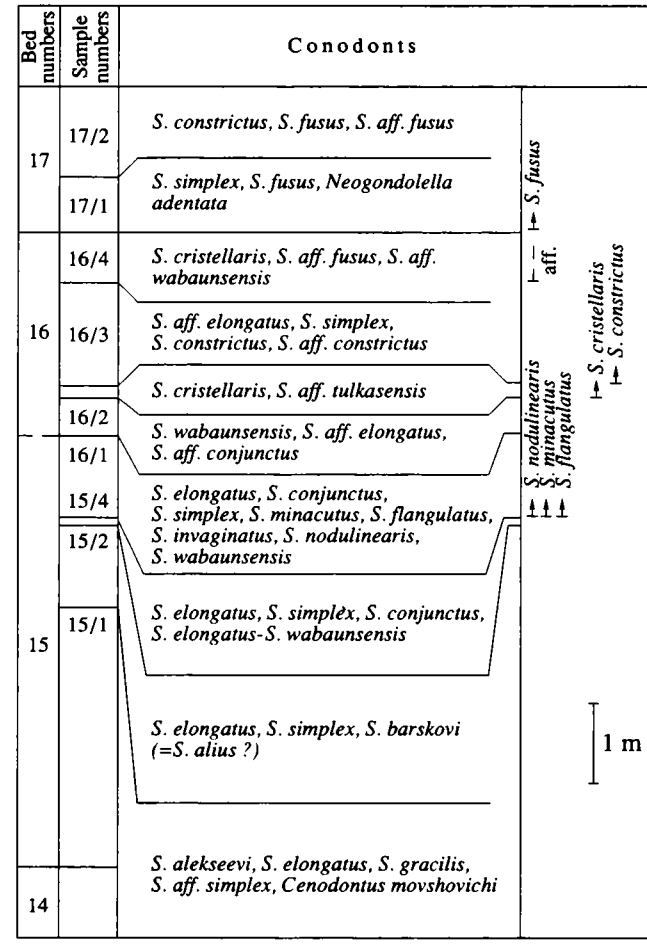


Fig. 3. Distribution of conodonts in the Usolka River section.

the early Asselian. It has short, sharply declining anterior branches of the parapet. At the beginning of the Permian, *Str. asselicus* Isakova, 1986 originated from it. The latter species demonstrates the same tendency of elongation of anterior tips of parapets, whose length sometimes exceeds the rest of the platform. The inner side of the platform can be ornamented with one or two nodes. The upper part of the *S. vulgaris–S. fusiformis* fusulinid zone was marked by the appearance of *Str. constrictus* Chernikh et Reshetkova, 1986 (Plate I, fig. *2*; Plate II, fig. 2), which became abundant in the overlying sediments. It has a narrower and curved S-shape platform with broad lapels formed by anterior elongated branches of the parapet. *Str. longissimus* Chernikh et Reshetkova, 1988, which appeared in the same interval, has the hypertrophically elongated platform and long branches of the parapet (Plate I, fig. *1*).

Phylogenetic development of species with accessory lobes from the *wabaunsensis–invaginatus–flangulatus*, *insignitus–nodulinearis*, *minacutus*, *cristellaris*, and *tulkasensis* groups. The major character of these species is the presence of accessory nodose lobes in different parts of the platform, although in general morphology, they still resemble *Str. elongatus*. *Str. wabaunsensis* Gunnell, 1933, appeared in the uppermost Gzhelian. It had the indistinctly separated lobe in the anterior part of the inner parapet (Plate I, fig. *8*). The lobe consists of irregularly located nodes, which can merge together. The distinct separation of the nodose inner lobe owing to the curvature of the inner side of the platform is typical of *Str. invaginatus* Chernikh et Reshetkova, 1986 (Plate II, figs. *10* and *13*). The appearance of the second accessory lobe on the inner side of the platform is the distinguishing feature of *Str. flangulatus* (Plate II, figs. *14* and *15*).

The independent appearance of a lateral lobe, composed of longitudinally located nodes in the middle part of the platform, is characteristic of *Str. insignitus* Akhmetshina, 1990, which appeared in the uppermost

Gzhelian, and of *Str. nodulinearis* Chernikh et Reshetkova, 1986 (Plate II, figs. *1*, *6*, *8*, and *9*).

Two species with rather peculiar morphology, *Str. minacutus* Barskov et Reimers sp. nov. (Plate II, figs. *3*, *5*, and *12*) and *Str. cristellaris* Chernikh et Reshetkova, 1988 (Plate II, figs. *4*, *7*, and *11*), appeared in the lower part of the Asselian. Their origin is still unclear, but most likely, they also originated from *Str. elongatus*. Based on conodonts from the Permian of the Southern Urals and on Gunnell's pictures, Chernykh (1987) defined *Str. acuminatus* as a form with an inner parapet distinctly separated from the main platform, which extends forward parallel to a free blade.

As indicated above, there are insufficient grounds to refer the Uralian form *Str. acuminatus* Gunnell sensu Chernikh to *Str. acuminatus* sensu Gunnell. At the same time, it undoubtedly differs from *Str. wabaunsensis*, the synonym of *Str. acuminatus* sensu Gunnell according to Ellison (1941). Below, we designate the Uralian species *Str. acuminatus* Gunnell sensu Chernikh as *Str. minacutus* sp. nov.

Str. cristellaris Chernikh et Reshetkova, 1988 demonstrates a highly specific morphology. Its inner anterior branch of the parapet is ornamented with short transverse ribs, but not with nodes or denticles as in other species. It is still unclear as to how the ribs were formed, either owing to the junction of nodes of the interrupted parapet typical of *Str. minacutus* with accessory nodes located in the median trough, or due to the simple broadening of nodes of the "normal" parapet, which is typical of *Str. elongatus*.

Str. tulkasensis Chernikh et Reshetkova, 1988 is known from somewhat younger sediments, but still from the *vulgaris–fusiformis* Zone. This form lacks ribs, but contains coarse folds in the anterior part of the inner parapet and a more massive platform. It may not be a separate species, but a herontic stage of *Str. cristellaris*.

DISTRIBUTION OF CONODONTS IN MAJOR SECTIONS OF BOUNDARY SEDIMENTS

The data on the conodont distribution in the Aidarlash section were obtained by the study of joint collections of Akhmetshina, Isakova, and Kozitskaya, which we examined together with Chernykh in 1988, as well as from new materials. We cite the bed numbers in this section according to Davydov *et al.* (1991). Figure 2 shows the data on the controversial interval of the section. The available materials suggest some conclusions discordant with previously accepted views.

(1) It was found that *Str. wabaunsensis* (Plate I, fig. *8*), whose appearance some authors correlate with the Carboniferous-Permian boundary (Isakova and Nazarov, 1986; Chernykh and Reshetkova, 1987), occurs in indubitable Carboniferous sediments, namely, in the *Daixina sokensis* fusulinid zone within the interval with a Carboniferous ammonoid assemblage (beginning with Bed 17).

(2) The appearance of conodonts unknown in Carboniferous deposits was recorded in the upper part of Bed 19. These species are *Str. nodulinearis*, *Str. asselicus*, *Str. flangulatus*, and *Str. minacutus* (*Str. acuminatus* sensu Chernikh). The Carboniferous ammonoid assemblage occurs 12 m downward the section, in the lower part of Bed 19. Undoubtedly Permian ammonoids were found in Bed 20 approximately 10 m above the first findings of the conodont assemblage (Davydov *et al.*, 1991). The first sphaeroschwagerinids appeared along with the conodont species cited above (Davydov *et al.*, 1991).

(3) The first occurrence of *Str. cristellaris*, the index species of the zone with the base suggested to be the Carboniferous-Permian boundary (Akhmetshina, 1990), was recorded in the upper part of Bed 20 about 10–12 m higher than the occurrence of Permian ammonoids, and 20–22 m higher than the appearance of the conodonts mentioned above.

(4) *Str. constrictus* and *Str. barskovi* also appeared within the *S. vulgaris–S. fusiformis* Zone in Bed 22. They both were suggested as index species of two zones, whose bases were believed to correspond to that of the *S. moelleri–P. fecunda* fusulinid zone.

The same succession of conodont species can be traced in the Usolka section, which is represented not by flyschoid, as in Aidarlash, but by basin facies of low thickness. The section was described by Chuvashov *et al.* (1991). These data were supplemented with materials obtained from samples bearing ammonoids (collected by A.A. Shkolin in 1990 and 1991). The conodont distribution and bed numbers in the boundary interval are cited according to Chernykh and Reshetkova (1988).

As Fig. 3 shows, the succession of key species is the same as in the Aidarlash section. Against the background of *Str. wabaunsensis* and *Str. elongatus* passing from below, *Str. minacutus* (*Str. acuminatus* sensu Chernikh), *Str. nodulinearis*, and *Str. flangulatus* together with *Str. invaginatus* appear beginning from sample 15/4. About 1.5–2 m above the level of samples 16/2 and 16/3, *Str. cristellaris* and *Str. constrictus* occur, which corresponds to Bed 22 of the Aidarlash section. The data on other Uralian sections (Barskov *et al.*, 1981; Isakova and Nazarov, 1986) and on wells in the Caspian syneclise (Akhmetshina, 1990; Akhmetshina *et al.*, 1984) confirm, or at least do not contradict the described succession of species appearance in the controversial boundary interval.

DISCUSSION

Thus, we can state that the appearance of the conodont assemblage with *Str. asselicus, Str. minacutus*, *Str. flangulatus*, *Str. invaginatus*, and *Str. nodulinearis* best of all corresponds to the Carboniferous-Permian

boundary defined in the ammonoid standard. Nowadays, this permits the determination of the place of the Carboniferous-Permian boundary in the conodont succession and its recognition with sufficient accuracy in sections from widely separated territories. In the proposed American standard, the Carboniferous-Permian boundary was placed in the Neva Limestone, Greenwood, Kansas (Ritter, 1991). Ritter correlated it with the "united *Str. wabaunsensis* and *Str. cristellaris* zones in the Soviet Union." The author evidently meant the zones suggested by Chernykh (Reshetkova and Chernykh, 1986). However, data on the Aidarlash section demonstrate that the bases of both zones do not correspond to the ammonoid level of the boundary. The presence of highly evolved *Str. barskovi* in the Neva limestone (Ritter, 1991), and *Str. flangulatus* from the underlying Folls City Limestone, can indicate that, provided correlation with the Aidarlash section, the boundary should be placed below the Neva Limestone, namely, within the Folls City and Red Eagle limestones. In the Nansen Formation of the Canadian Arctic, *Str. nodulinearis*, which marks the beginning of the Permian in the Uralian sections, occurs at the level corresponding to the base of the *S. vulgaris–S. fusiformis* Zone (Henderson, 1991).

However, this by itself is not enough for the formal biostratigraphic determination of the boundary according to conodonts. There is a need to propose a biologic boundary determination with the indication of an ancestor and descendant species in a certain lineage and, based on these data, to approve the status of subdivisions distinguished within the boundary interval as corresponding to formal biostratigraphic zones.

As the table shows, none of the previously suggested zonations satisfies the stated requirements.

Zonations using *Str. wabaunsensis* as an indicator of the boundary (Isakova and Nazarov, 1986; Chernykh and Reshetkova, 1987) are inadequate. The earliest occurrence of this species was recorded in the sediments with the Carboniferous ammonoid assemblage within the *sokensis* fusulinid zone. We should also reject zonations, where the boundaries are not defined by the first occurrence level of index species and separate only concurrent zones of species distribution above and below the boundary (Chuvashov, 1990). The *Str. cristellaris* Zone (Chernykh and Reshetkova, 1987) most closely corresponds to the boundary drawn in the ammonoid standard. However, it was distinguished in the facies, which lack fusulinids, and its base was not controlled by ammonoids. In the Aidarlash section, this species was recorded substantially above the base of the boundary marked by ammonoids.

Therefore, the presence of *Str. cristellaris* and *Str. barskovi*, which occur at approximately the same level, reliably indicates the Permian age of deposits, but cannot exactly define the boundary.

As discussed earlier, conodonts *Str. minacutus*, *Str. flangulatus*, *Str. nodulinearis*, and *Str. asselicus*, which were missing in the underlying Carboniferous sediments, occur at a level almost coinciding with the appearance of the Permian ammonoid assemblage. But none of these forms was used as an index species of a formal conodont zone. In principle, the available data enables any one of these species to be chosen for distinguishing a zone with the base best corresponding to the boundary in the ammonoid standard. However, the introduction of one more zonal scheme is not presently urgent for the following reasons: (1) Despite the taxonomic revision partly made herein, the taxonomic and, possibly, nomenclature status of some species is not approved. (2) In spite of the elucidated phylogenetic relations, they are not confirmed in successive and extensive sections, where the transformation of species can be traced in consecutive temporal intervals. (3) The ecologic confinement of species still remains largely unclear, though different species groups, for instance, narrow- and broad-platform ones, obviously inhabited somewhat dissimilar environments.

It is precisely these obscure questions that represent problems for further investigations. We consider the lineages of *Str. alius* ⇒ *Str. barskovi*, *Str. elongatus* ⇒ *Str. cristellaris*, and *Str. elongatus* ⇒ *Str. minacutus* as the most suitable to trace the species transformation, justifying the formal determination of the boundary.

Two former lineages appear to be the most appropriate. According to the available data, *Str. barskovi* and *Str. cristellaris* are certainly known from deposits above the level of the ammonoid boundary, and after the detailed taxonomic research on transitional forms from continuous monofacial sections, the level of their first occurrence can approach the boundary defined by ammonoids.

CONCLUSION

(1) Close to the Carboniferous-Permian boundary, two phylogenetic tendencies in the evolution of the *Streptognathodus* genus were recorded in passing from convincingly Carboniferous to Permian species. The tendencies depict modifications of anterior branches of platform parapets, namely, the elongation of anterior branches (*Str. alius–barskovi–fusus*, *simplex–asselicus–constrictus*) and changes of the inner parapet morphology (*Str. elongatus–minacutus*, and *Str. cristellaris*).

(2) The level closest to the ammonoid standard of the Carboniferous-Permian boundary is within the transition interval between the first and second members of the cited lineages.

(3) The existing conodont zonations for the boundary interval are inadequate for the formal determination of the Carboniferous-Permian boundary based on these fossils.

(4) The phylogenetic substantiation of the boundary and its formal determination require a detailed study of materials from extensive sections of boundary sediments and a new taxonomic revision of key species.

SYSTEMATIC DESCRIPTION

Streptognathodus minacutus Barskov et Reimers sp. nov.

Plate II, figures *3*, *5*, and *12*

Streptognathodus acuminatus: Chernykh and Reshetkova, 1987, p. 34, Pl. 7, fig. *5*; Akhmetshina, 1990, Pl. 1, figs. 5, and 8; Barskov and Reimers, 1992, Pl. 1, fig. *4*.

Holotype: Moscow State University (MGU) no. 262/286, Samp. 16/1, Usolka River, Southern Urals, Lower Permian, Asselian, Plate II, fig. 3.

Description. The platform element is scaphoid, lanceolate, with a narrow platform, whose lateral parts slightly project beyond the ornamented parapet. The axial part of the platform is flat in the side view. It is ornamented with transverse ribs separated by the median trough. The median trough divides the platform into two, outer and inner, lateral parapets. The outer parapet is narrower and undivided, while the inner one is divided at the anterior end of the platform by a furrow beginning from the posterior end of the carina and opening outward at the inner side of the platform. Anterior branches of parapets are elongated, extending along lateral sides of the free blade for one-half of its length. The anterior branch of the inner parapet forms a broad lapel and bears short transverse ribs. The carina is short and smooth, sometimes consisting of small nodes. The free blade is straight, of medium length, and formed by a row of denticles merged at their base. Denticles are compressed from the sides. The first three denticles of the anterior margin of the species are triangular in the side view. The asymmetrical basal cavity occupies the whole aboral surface of the platform. Lateral margins of the basal broadening somewhat project beyond the edges of the ornamented part of the platform, which is more evident from its outer side. The basal cavity continues under the free blade as a basal slit.

Comparison. *Str. minacutus* is distinguished from all *Streptognathodus* representatives by a peculiar rupture of the parapet at the inner side of the platform.

Distribution. The Asselian Stage of the Lower Permian in the Urals and Caspian syneclise.

Material. Over 30 specimens from the Usolka and Aidarlash sections of the Southern Urals and wells of the Caspian syneclise.

Streptognathodus barskovi (Kozur, 1976)

Plate I, figs. *3–5*, *10–14*

Gnathodus barskovi: Kozur, 1976, Taf. 3, figs. *2*, *4*, *6*; fig. 6—holotypus; Kozur, 1978, Taf. 2, figs. *11–14*; Movshovich, Kozur *et al.*, 1979, Pl. 1, fig. *7*, Pl. 4, fig. *8*.

Streptognathodus barskovi: Barskov *et al.*, 1981, Pl. 2, fig. 14, p. 84; Chuvashov *et al.*, 1983, Pl. 31, figs. 12–14; Isakova and Nazarov, 1986, Pl. 32, figs. 12, 13; Chernykh and Reshetkova, 1987, Pl. 7, figs. 1, 10, 11; Akhmetshina, 1990, Pl. 1, fig. 17; Barskov and Reimers, 1992, Pl. 1, fig. 7.

Holotype: Middle Urals, Tabantal River, middle fusulinid zone of the Asselian.

Topotypes: Paleontology Department, Moscow State University, samp. no. 262/458-469, Middle Urals, Tabantal River, samp. 591, Lower Permian, Asselian, Plate I, figs. 4, 5, 10, 11, 13.

Description. The platform element is scaphoid with a wide basal cavity and massive platform. The basal broadening projects outside the ornamented part of the platform. The posterior margin of the platform is oval or slightly sharpened. The platform surface is spatulate, bearing transverse ribs separated in the middle by a median trough. Different specimens have the trough either deep and distinctly separating the ribs, or resembling a shallow axial furrow. In the latter case, ribs can be partly merged. The anterior portion bears a short smooth carina, which is separated from anterior branches of the parapet by deep troughs. Anterior parapet branches are elongated and extend, especially the outer one, for two-thirds of the length of the free blade. The ornamentation on lateral branches of the carina is represented by short transverse ribs or broadened nodes. The free blade is of medium length, almost totally flanked by anterior branches of parapets, and consists of compressed denticles merged at the base. The height of the discrete part of denticles increases forward. The most anterior denticle is short. The aboral surface bears the basal cavity, occupying the whole platform and basal broadening. The basal cavity continues under the free blade in the form of a basal slit.

Comparison. The species is distinguished from *Str. alius* Akhmetshina by long anterior branches of parapets. It differs from *Str. fusus* Chernikh et Reshetkova by a broadly rounded, but not sharpened outline of posterior margin, as well as by the lack of wide lapels in anterior parts of the platform parapet.

Distribution. The Asselian Stage of the Middle and Southern Urals and Caspian syneclise.

Material. Over 35 well preserved specimens from the Tabantal, Usolka, and Aidarlash sections, and also from wells of the Caspian syneclise.

Reviewers E.Ya. Leven and V.A. Aristov

REFERENCES

Akhmetshina, L.Z., Conodonts from Carboniferous-Permian Boundary Sediments of Eastern Margin of the Caspian Syneclise, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1990, vol. 65, no. 1, pp. 80–88.

Akhmetshina, L.Z., Barskov, I.S., and Isakova, T.N., Gzhelian, Asselian, and Sakmarian Conodonts. Russian Platform, Southern Urals, and Caspian Syneclise, in *Verkhnii karbon*

SSSR (Upper Carboniferous of the USSR), Moscow: Nauka, 1984, pp. 51–54.

Baars, D.L., Maples, K.G., Ritter, S.M., *et al.*, Redefining of the Pennsylvanian-Permian Boundary in Kansas, Midcontinent, USA, in *Tezisy mezhdunarodnogo kongressa "Permskaya sistema zemnogo shara"* (Proc. Int. Congr. "Permian System of the Earth"), Perm', 1991, pp. 16–17.

Barskov, I.S., Upper Carboniferous and Asselian Zonation by Conodonts and Problems of Its Improvement, in *Verkhnii karbon SSSR* (Upper Carboniferous of the USSR), Moscow: Nauka, 1984, pp. 102–107.

Barskov, I.S., Conodont Distribution at the Carboniferous-Permian Boundary, in *Osnovnye sobytiya istoricheskogo razvitiya tsefalopod* (Major Events of the Cephalopod Historic Development), Available from VINITI, 1991, Moscow, no. 1916-B91, pp. 74–83.

Barskov, I.S., Isakova, T.N., and Schastlivtseva, N.P., Conodonts from Gzhelian–Asselian Boundary Beds, Southern Urals, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1981, no. 5, pp. 78–87.

Barskov, I.S., Khalymbadzha, V.G., Kosenko, Z.A., *et al.*, Terminology and Description Mode of Platform Conodonts, *Paleontol. Zh.*, 1975, no. 3, pp. 121–126.

Barskov, I.S. and Reimers, A.N., Main Features of the Conodont Historic Development in the Early Permian, *Vestn. Mosk. Univ., Ser. 4: Geol.*, 1992, no. 2, pp. 44–53.

Bogoslovskaya, M.F., Leonova, T.B., and Shkolin, A.A., Ammonoids from the Aidarlash Section and Carboniferous-Permian Boundary, in *Osnovnye sobytiya istoricheskogo razvitiya tsefalopod* (Major Events of the Cephalopod Historic Development), Available from VINITI, 1991, Moscow, no. 1916-B91, pp. 42–73.

Chernykh, V.V. and Chuvashov, B.I., Zonal Subdivision of the Lower Permian by Conodonts, in *Tezisy mezhdunarodnogo kongressa "Permskaya sistema zemnogo shara"* (Proc. Int. Congr. "Permian System of the Earth"), Perm', 1991, p. 86.

Chernykh, V.V. and Reshetkova, N.P., Biostratigraphy and Conodonts of Carboniferous and Permian Sediments in the Western Slope of the Southern and Middle Urals, Sverdlovsk: Ural. Nauch. Tsentr Akad. Nauk SSSR, 1987.

Chernykh, V.V. and Reshetkova, N.P., Zonal Subdivision of Carboniferous–Permian Boundary Sediments from the Western Ural Slope by Conodonts, in *Biostratigrafiya i litologiya verkhnego paleozoya Urala* (Upper Paleozoic Biostratigraphy and Lithology of the Urals), Sverdlovsk: Ural. Otd. Akad. Nauk SSSR, 1988.

Chuvashov, B.I., Permian of the Urals, Lower Series, Lower-Upper Permian Boundary Sediments, in *Problemy stratigrafii Urala* (Stratigraphic Problems of the Urals), Sverdlovsk: Ural. Otd. Akad. Nauk SSSR, 1990, pp. 30–62.

Chuvashov, B.I., Dyupina, G.V., Mizens, G.A., and Chernykh, V.V., Krasnousol'sk Section, in *Mezh. kongress "Permskaya sistema zemnogo shara". Putevoditel' ekskursii. Ch. II. Razrezy permskoi sistemy basseina r. Beloi* (Int. Congr. "Permian System of the Earth". Guide Book for Excursions, Pt. II: Permian Sections from the Belaya River Basin), Sverdlovsk: Ural. Otd. Akad. Nauk SSSR, 1991, pp. 5–47.

Chuvashov, B.I., Leven, E.Ya., Davydov, V.I., *et al.*, *Pogranichnye otlozheniya karbona i permi Urala, Priural'ya i Srednei Azii* (Carboniferous–Permian Boundary Sediments of the Urals, Ural Region, and Central Asia), Moscow: Nauka, 1986.

Chuvashov, B.I., Mizens, G.A., Dyupina, G.V., *et al.*, *Opornyi razrez verkhnego karbona i nizhnei permi tsentral'noi chasti Bel'skoi vpadiny* (Upper Carboniferous and Lower Permian Reference Section from the Central Bel'sk Depression), Sverdlovsk: Ural. Nauch. Tsentr Akad. Nauk SSSR, 1983.

Davydov, V.I., Barskov, I.S., Bogoslovskaya, M.F., *et al.*, Carboniferous–Permian Boundary in the USSR and Its Correlation, in *Tezisy mezhdunarodnogo kongressa "Permskaya sistema zemnogo shara"* (Proc. Int. Congr. "Permian System of the Earth"), Perm', 1991, p. 33.

Davydov, V.I., Popov, A.V., Bogoslovskaya, M.F., *et al.*, Aidarlash Section, in *Mezh. kongress "Permskaya sistema zemnogo shara". Putevoditel' ekskursii. Ch. II. Vyp. 2. Razrezy permskoi sistemy basseina r. Ural* (Int. Congr. "Permian System of the Earth". Guide Book for Excursions, Pt. II, no. 2, Permian Sections from the Ural River Basin), Sverdlovsk: Ural. Otd. Akad. Nauk SSSR, 1991, pp. 54–84.

Ellison, S.P., Revision of the Pennsylvanian Conodonts, *J. Paleontol.*, 1941, vol. 15, no. 2, pp. 107–143.

Gunnell, F., Conodonts and Fish Remains from the Cherokee, Kansas City, and Wabaunsee Groups of Missouri and Kansas, *J. Paleontol.*, 1933, vol. 7, no. 3, pp. 262–298.

Henderson, I., Distinguishing of the Carboniferous-Permian Boundary in the Western and Arctic Canada, in *Tezisy mezhdunarodnogo kongressa "Permskaya sistema zemnogo shara"* (Proc. Int. Congr. "Permian System of the Earth"), Perm', 1991, p. 136.

Isakova, T.N. and Nazarov, B.B., *Stratigrafiya i mikrofauna pozdnego karbona–rannei permi Yuzhnogo Urala* (Late Carboniferous–Early Permian Stratigraphy and Microfauna of the Southern Urals), Moscow: Nauka, 1986.

Kozur, H., Beiträge zur Stratigraphie des Perms, *Geol. Palaontol. Mitt. Innsbruck*, 1975, vol. 5, pp. 1–44.

Kozur, H., Probleme der Abgrenzung und Gliederung des Perms, *Beiträge zur Stratigraphie des Perms. T. 1*, Freib. Forsh., 1977, vol. C-319, pp. 79–121.

Kozur, H., Die Conodontenchronologie des Perms, in *Beiträge zur Stratigraphie des Perms.*, Leipzig, 1978, vol. C-334, pp. 85–161.

Kozur, H. and Mostler, H., Neue Conodonten aus dem Jungpaleozoikum und der Trias, *Geol. Palaontol. Mitt. Innsbruck*, 1976, vol. 6, no. 3, pp. 1–33.

Mezhdunarodnyi kongress "Permskaya sistema zemnogo shara". Putevoditel' geologicheskikh ekskursii. Ch. II, Vyp. 1. Razrezy permskoi sistemy basseina r. Beloi (zapadnyi sklon Yuzhnogo Urala) (Int. Congr.: "Permian System of the Earth". Guidebook for Geological Excursions, Pt. II, issue 1: Permian Sections of the Belaya River Basin, Western Slope of the Southern Urals), Sverdlovsk: Ural. Otd. Akad. Nauk SSSR, 1991.

Mezhdunarodnyi kongress "Permskaya sistema zemnogo shara". Putevoditel' geologicheskikh ekskursii. Ch. II. Vyp. 2. Razrezy permskoi sistemy basseina r. Ural (zapadnyi sklon Yuzhnogo Urala) (Int. Congr. "Permian System of the Earth", Guidebook of Geological Excursions. Pt. II, no. 2:

Permian Sections of the Ural River Basin, Western Slope of the Southern Urals), Sverdlovsk: Ural. Otd. Akad. Nauk SSSR, 1991.

Movshovich, E.V., Kozur, H., Pavlov, A.M., *et al.*, Lower Permian Conodont Assemblages of the Ural Region and Problems of Correlation, in *Konodonty Urala i ikh Stratigraficheskoe Znachenie* (Conodonts of the Urals and Their Stratigraphic Significance), Sverdlovsk: Ural. Nauch. Tsentr Akad. Nauk SSSR, 1979, pp. 94–131.

Postanovlenie Mezhvedomstvennogo stratigraficheskogo komiteta i ego postoyannykh komissii, Vyp. 22 (Resolution of the Interdepartmental Stratigraphic Comittee and Its Comissions, issue 22), Leningrad: Vses. Geol. Inst., 1985.

Reshetkova, N.P. and Chernykh, V.V., New Species of Asselian Conodonts from the Western Ural Slope, *Paleontol. Zh.*, 1986, no. 4, pp. 108–113.

Ritter, S.M., Stratigraphic Distribution of Late Carboniferous–Early Permian (Gzhelian–Asselian) Conodonts in the Midcontinent USA Sections and Preliminary Correlation with the Conodont Succession in Russia, in *Tezisy mezhdunarodnogo kongressa "Permskaya sistema zemnogo shara"* (Proc. Int. Congr. "Permian System of the Earth"), Perm', 1991, p. 72.

Stratigraphy and Geological Correlation, Vol. 4, No. 5, 1996, pp. 440–449. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 5, 1996, pp. 25–34.
Original Russian Text Copyright © 1996 by Povysheva, Ustritskii.
English Translation Copyright © 1996 by MAIK Nauka/Interperiodica Publishing (Russia).

Permian Deposits in the Novaya Zemlya Islands

L. G. Povysheva and V. I. Ustritskii

All-Russian Research Institute of Geology and Mineral Resources of the World Ocean, prosp. Maklina 1, St. Petersburg, 190121 Russia

Received September 8, 1993; in final form, December 26, 1994

Abstract—The Permian deposits of the whole Novaya Zemlya Archipelago are described for the first time. Five facies zones are distinguished and described. The age of brachiopod assemblages studied earlier was revised. Depositional environments are discussed. Distinctions are made between the formation of Permian deposits of Novaya Zemlya and the Ural Foredeep.

Key words: *Novaya Zemlya, stratigraphy, lithology, Permian, fauna, flora, facial zonation.*

The Permian deposits of Novaya Zemlya, covering about a third of the island area (Fig. 1), were discussed in several important but now outdated publications (Alferov, 1935; Miloradovich, 1936a; Petrenko, 1936; Rysyukov, 1936). The same is true of brachiopod description (Miloradovich, 1936). Fauna studied by Miloradovich and assigned to the Lower Permian appeared to be Upper Permian (Ustritskii, 1984), whereas most of the brachiopods earlier described by Likharev and Einor appeared to be Carboniferous.

The monograph *Permian Deposits of Novaya Zemlya* (1981) mainly represents the detailed description of the Permian section of Mezhdusharskii Island and residing fauna and flora. There are also several publications dedicated to the Permian stratigraphy of separate regions (Matveev *et al.*, 1989; Ustritskii, 1981; Cherkesov and Makarov, 1982), sedimentation environment (Voyakovskii, 1988; Platonov *et al.*, 1992; Povysheva and Ustritskii, 1988; Korago and Kovaleva, 1980), and description of ammonoids (Bogoslovskaya *et al.*, 1982). More than 40 bryozoan species from the upper Permian deposits of Novaya Zemlya are described in the monograph *Permian Bryozoans of the Arctic Regions* (Morozova and Kruchinina, 1986).

The books *Geology of Soviet Arctic Regions* (1957), *Geology of the USSR*, volume 26, and *Soviet Arctic Islands* (1970) presenting a summary on Permian deposits of Novaya Zemlya are based on outdated material.

It is pertinent to note that from 1977 to 1990, the West-Arctic Team of the Polar Marine Prospecting Expedition (PMPE) of the PGO *Sevmorgeologiya* carried out a geological survey of the whole territory of Novaya Zemlya under the supervision of L.G. Pavlov. Permian deposits were also studied by K.K. Makarov, V.P. Matveev, V.F. Nepomiluev, V.V. Orgo, E.G. Platonov, O.P. Timofeev, G.V. Trufanov, G.E. Chernyak, and others.

Determinations of conodonts carried out by N.N. Sobolev were of special importance as they allowed the fossil-free sequences of the eastern part of the island to be assigned to the Permian.

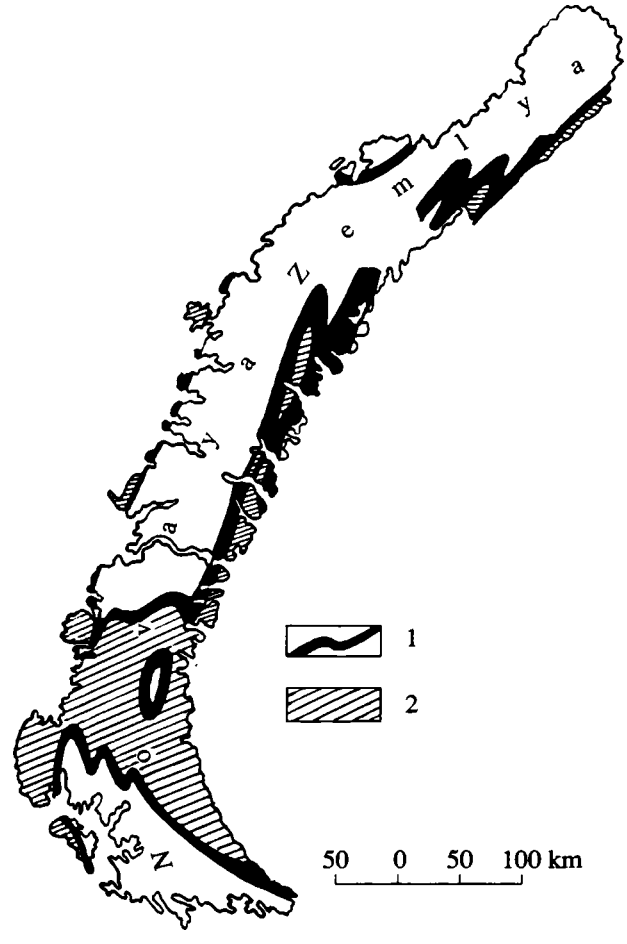


Fig. 1. The occurrence of Permian deposits on Novaya Zemlya. (1) Lower Permian; (2) upper Permian.

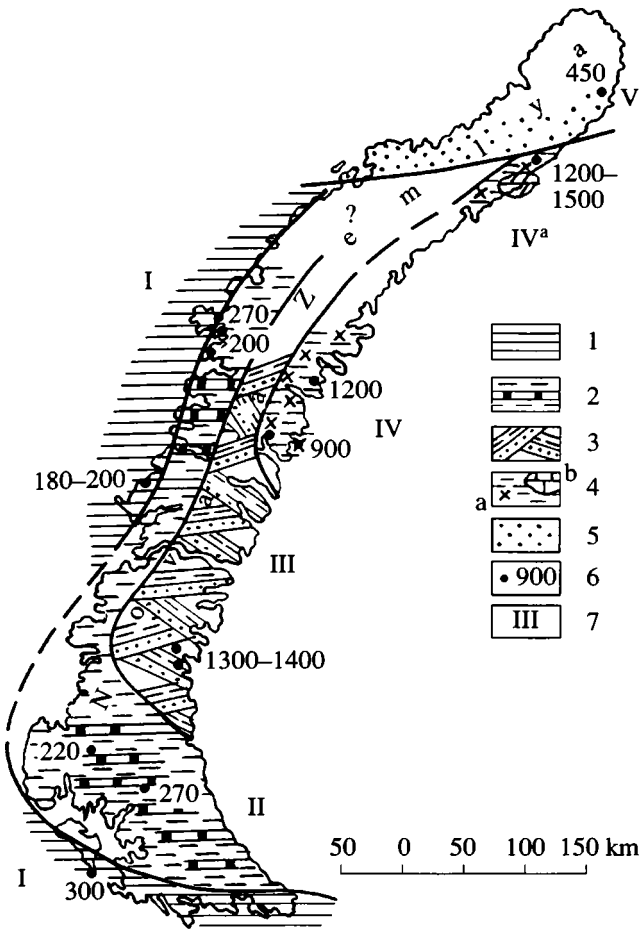


Fig. 2. Scheme of the early Permian (the Asselian) facial zones.

(1) Upper part of the continental slope, mudstones prevail; (2) middle part of the continental slope, siliceous mudstones with strata of manganese ore; (3) base of the continental slope, contourites; (4) basin floor, siliceous-clayey rocks (a), ditto, olistostromes (b); (5) shelf, calcareous sandstones; (6) location of principal section and the thickness of the lower Permian deposits; (7) number of the structural-facial zone and the section type.

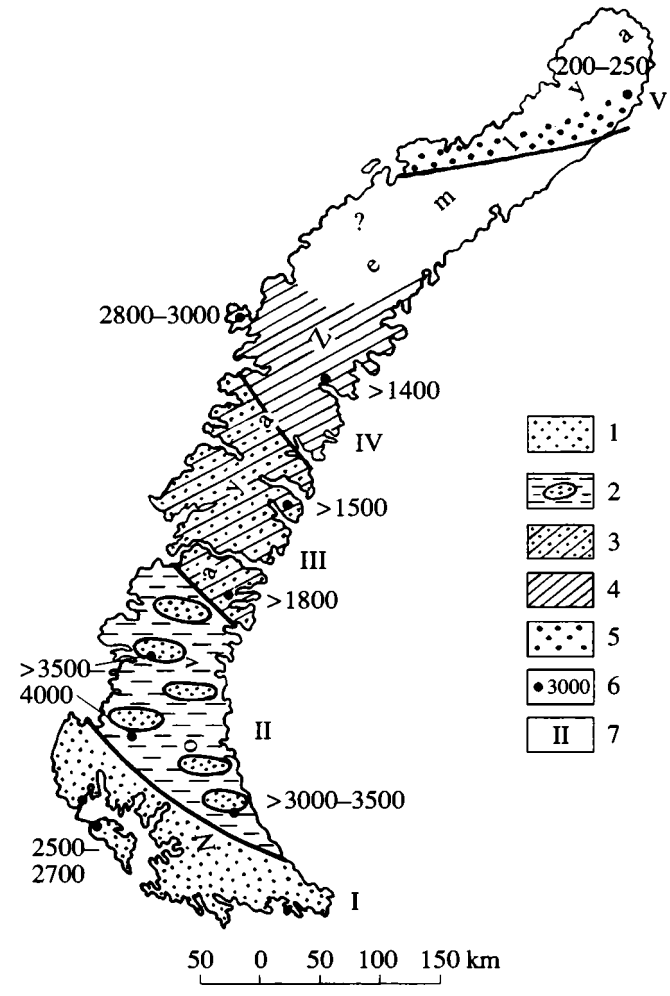


Fig. 3. Scheme of facial zones at the beginning of the late Permian (the first half of the Ufimian).

(1) Continental slope, mudstones, siltstones, sandstones; (2) foot of the slope, olistostromes; (3) basin floor, sandy turbidites; (4) basin floor, clayey turbidites; (5) shelf, calcareous sandstones; (6) location of principal sections and the thickness of upper Permian deposits; (7) number of the structural-facial zone and the type of the section.

As a result, a distribution of Permian deposits was revealed (Fig. 1), principal types of sections were established, and a pioneer scheme of facies zonation was elaborated, which is used in the present work.

Permian deposits are represented on Novaya Zemlya by a terrigenous, mainly marine, sequence up to 6–6.5 km thick. The facial zonation of the Early Permian shows the development of fossil-free abyssal deposits in the east of the central part of the archipelago, which gradually change into shallower deposits in the south, west and north (Fig. 2). The terrigenous material was derived in minor amounts from uplifts located west of Novaya Zemlya; therefore, Lower Permian deposits are usually hundreds of meters thick, ranging up to 1000–1500 m at the foot of the continental slope only.

At the beginning of the Late Permian, the influx of the terrigenous material from the Urals, which filled in a deep basin in the south, increased greatly. In this connection, the character of the facies zonation changed (Fig. 3), and the thickness of deposits abruptly increased to 4–5 km.

The facies zonation scheme was compiled for the earliest Late Permian. During the Late Permian, the basin was progressively being filled with terrigenous material; therefore, in all sections, the deep-water sediments grade into shallow-water and then paralic deposits. For instance, on Mezhdusharskii Island, the Lower Permian sequences are represented by deep-water deposits, the upper Ufimian sequences by shallow-water deposits, the Kazanian–lower Tatarian strata by paralic deposits, and the upper Tatarian beds by conti-

nental deposits. The boundary between shallow- and deep-water deposits gradually shifts northward. By the end of the Permian, the basin was completely filled with sediments. The upper Permian paralic deposits occur even on the North Island of Novaya Zemlya near the Admiralty Peninsula, whereas the lower Triassic deposits are continental everywhere.

Five types of sections were distinguished among the upper and lower Permian deposits (Figs. 2–4). Although the boundaries of facies zones do not coincide for the early and late Permian, the type sections of the zones are located close to each other. Therefore, they are shown in Fig. 4 as single ones although respective areas are not quite identical; note that one should refer to Figs. 2 and 3 when reading the text.

Five facies zones and relevant types of sections are distinguished for the Permian deposits of Novaya Zemlya.

Sections of the first type (Zone I) are in the southwest of the South Island of Novaya Zemlya. Lower Permian deposits of the same type extend as a narrow strip along the western coast of the North Island from the Mityushikha Inlet to the Admiralty Peninsula. The deposits are represented by the Glazov Formation (C_3–P_1gl), identified by O. Kholtedal in 1924. The stratotype of the formation was not indicated, and a section on the Kostin Nos Cape (the southern edge of the Mezhdusharskii Island) was taken as a lectostratotype. The Glazov Formation is of uniform structure. Dark-gray and black mudstones and silty mudstones with calcareous and dolomite concretions dominate in it. Two interlayers of sandstones up to 2 m thick occur in the lower part and at the top of the section, and a calcarenite lens at its base. Calcarenites yielded the Middle Carboniferous redeposited foraminifers. The thickness of the formation ranges from 180 to 300 m. Organic remains are absent. Based on the position in the section between the Kasimovian (with fauna) and Upper Permian deposits, the formation was assigned to the Late Carboniferous (Gzhelian)–Early Permian (pre-Kungurian?). The deposits correspond to the upper part of a basin slope.

In the Late Permian, Zone I occupied a larger area on the South Island of Novay Zemlya (Fig. 3). A complete upper Permian section is exposed on the Mezhdusharskii Island and the Gusinaya Zemlya Peninsula, where stratotypes of the Belushii, Gusinaya Zemlya, Shchadrovskii and Admiralty formations are represented. The section is described in detail in *Permian Deposits of Novaya Zemlya* (1981); the book also comprises the complete lists of fauna and flora, as well as pictures of most characteristic forms. Productoids of this zone are described in the work of Ustritskii (1984); therefore, we introduce the lists in a shorthand form.

The Belushii Formation (P_2bl) is made up of alternating members of massive and platy sandstones (60–70% of the formation volume), siltstones, mudstones, and members of their interbedding. The sandstones are polymictic, gray, fine-grained, rarely medium-grained. The section of the formation on the Mezhdusharskii Island and the Belushii Peninsula is uniform, and its thickness is 350–500 m. Eastward, in the Yuzhnaya Tainaya River basin, the formation is subdivided into two parts: the lower, 200–300 m thick, consisting mainly of sandstones, and the upper, 450–500 m thick, representing equally alternating sandstones and mudstones with individual interlayers of mixtites and separated olistoliths of Devonian and Carboniferous limestones up to 7 m thick.

The total thickness of the formation ranges from 350–500 m in the west to 700–800 m in the east. Organic remains are abundant in the west in shallow-water sections, which yielded foraminifers, bivalves, brachiopods, and plant remains from the upper part of the sections. Foraminifers are represented by *Nodosaria hexagona* Tscherd., *N. bogatirevi* Jg., *Pseudonodosaria fanatica* Sossip., *Rectoglandulina beringi* A.M.-Maclay, *Frondicularia amygdalleformis* Gerke, *F. hemiinflata* Gerke, and others. The most characteristic bivalves are *Myonia komiensis* (Masl.), and *Atomodesma* sp., and the most typical brachiopods are *Arctochonetes transitions* (Krot.), *Anemonaria variabilis* Ustr., *Phynchopora geinitziana* (Vern.), *Kitakamithyris magna* (Mil.), and others.

Plant remains are represented by the typical Pechora assemblage, which includes *Sphenophyllum* sp., *Callipteris* sp., *Phylladoderma arberi* Zal., and others. Prior to the investigations carried out on Novaya Zemlya, this assemblage, primarily revealed in the Pechora basin, was assigned to the Kazanian–Tatarian. Some brachiopod species found together with the Pechora assemblage and considered then as typical of the early Permian only allowed a substantiation of the Ufimian age of deposits characterized by such an unusual combination of fossils. The Ufimian age of the lowest Pechora Group is also assumed for a new unified scheme of Permian deposits of the Urals, which is under preparation now.

The Gusinaya Zemlya Formation (P_2gz) is composed of marine, relatively shallow-water sediments with a rich benthic fauna and flora. It is subdivided into two subformations.

The lower Gusinaya Zemlya Subformation (P_2gz_1) is represented by siltstones and mudstones with rare sandstone interlayers. Calcareous, marly, sideritic and calcareous–phosphatic concretions and lenses, as well as lenses that are bright yellow on the weathering surface, and interlayers of siderite-bearing siltstones are characteristic of the subformation. The subformation is 550–650 m thick. The marine fauna is rare.

Concretions and carbonate interlayers enclose foraminifers *Nodosaria hexagona* Tscherd., *N. cuspidatula* Gerke, *Lingulonodosaria clavata* Paal., *Dentalina kalinkoi* Gerke, and *Rectoglandulina beringi* A.M.-Maclay. Bivalves *Atomodesma* sp., brachiopods *Orbiculoidea* aff. *jangarensis* Ustr., and *Strophalosia*

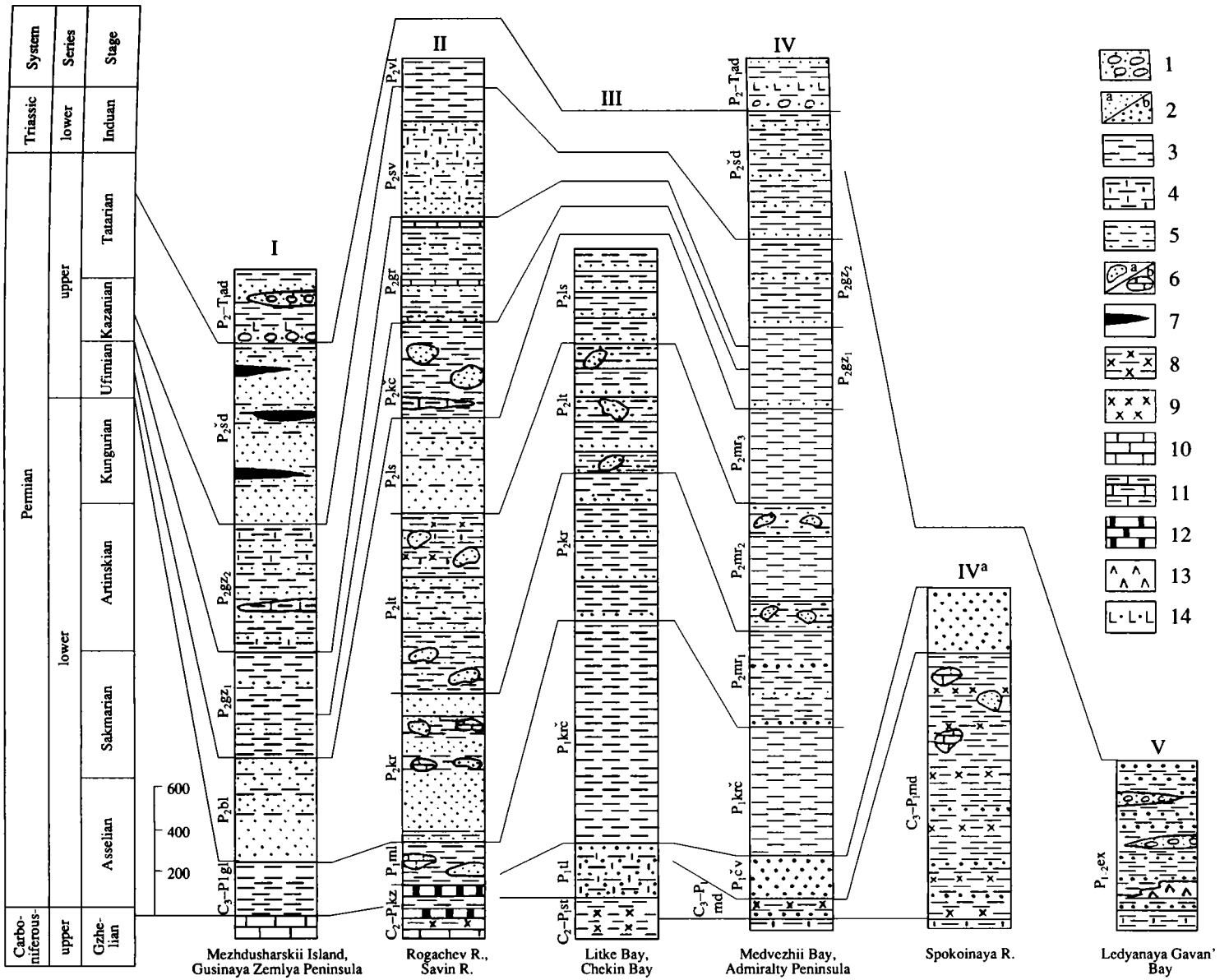


Fig. 4. Correlation of principal sections of the Permian deposits (numbers of sections correspond to numbers of structural-facial zones in Figs. 2 and 3).

(1) Conglomerates, gravelstones; (2) sandstones: a—polymictic, b—quartzitic; (3) siltstones and mudstones; (4) siltstones and siliceous mudstones; (5) mixtites; (6) olistoliths: a—sandstone, b—limestone; (7) coals; (8) siliceous mudstones; (9) siliceous rocks; (10) limestones; (11) clayey limestones; (12) rhodochrosite rocks; (13) gipsum and anhydrite; (14) basaltic tuffs.

sp. are found in the subformation. Flora remains represented by forms similar to those in the Belushii Formation are more common. There is some evidence for the presence of the Late Permian Ammonoidea *Neogeoceras* sp. (Bogoslovskaya *et al.*, 1982), although its origin from the section is doubted.

The upper Gusinaya Zemlya Subformation (P_2gz_2) consists of alternating members of massive mudstones or siltstones and members of the same rocks with the rhythmic structure. The thickness of the rhythms is 60–80 m, and that of the subformation is 500–600 m. The subformation yielded richer fauna than the lower subformation with brachiopods prevailing over other fossils. *Spitzbergenia alferovi* Milor. appears in the upper part of the section; *Bathymyonia* aff. *pajeri* Toula, *Kochiproductus plexicostatus* Dunbar, *Megousia weyprechti* (Toula) and other forms are also present. Plant remains are represented by *Cordaites* (?) cf. *iljinskiensis* (Radcz.) S. Meyen, *Rufloria synensis* (Zal.) S. Meyen, *Cardiolepis piniformis* Neub. Foraminifers *Nodosaria pseudolata* Karav., *Pseudonodosaria ventrosa* Schleifer, *Frondicularia dilemma* Gerke, and *Rectoglandulina pygmeaformis* (A.M.-Maclay) are found near the top of the subformation. By the appearance of *Spitzbergenia* in the upper part of the section, the subformation was assigned to the Ufimian–Kazanian, although this dating was based on correlation with the Arctic Sea sections rather than with the type section of the Russian platform, as the Kazanian faunas of these regions contain no common forms.

The Shadrovskii Formation (P_2sd) crops out in major synclines on Mezhdusharskii Island and the Gusinaya Zemlya Peninsula.

The formation is composed of paralic sediments: gray and greenish-gray obliquely laminated sandstones, siltstones and mudstones. The formation rocks enclose abundant carbonized plant detritus or coal crumb, coal bands, fragments of petrified tree trunks up to 80 cm in diameter, fauna and flora, and ripple marks on bedding planes. The formation has a rhythmic structure. Any rhythm always begins with sandstones, sometimes containing pebbles of underlying mudstones at the base. Upsection, sandstones grade into siltstones, then clayey siltstones, and the rhythm ends with uniform mudstones.

On Mezhdusharskii Island, the formation is 850 m thick. Organic remains are abundant and diverse. Apart from common Kazanian species, the Shadrovskii Formation yielded some additional foraminifer species: *Pseudonodosaria fanatica* Sossip., *Frondicularia parri* Crespin, *F. pseudotriangularis* Gerke, *F. novosemelica* Sossip, *F. gigantea* Sossip and others. Brachiopods are represented by prevailing *Lingula freboldi* Gobb., *Spitzbergenia alferovi* Milor., *Strophalosia multituberculata* Ustr., *Megousia weyprechti* (Toula), *Stepanowiella litkei* Milor, and others, bivalves by *Myonia umbonata* Muromz., *Atomodesma variabilis* (Wann.), *A. costata* (Popor.), *Cyrtorostra laticostata* (Netsch.) and others. Goniatites *Neogeoceras glabrum* Bogosl. were found in the upper part of the formation. The plant assemblage is diverse. Among the Kazanian and Tatarian species, *Cordiates* cf. *minax* (Gorel.) S. Meyen, *C. iljinskensis* (Radcz.) S. Meyen, *Rhipidopsis ginkgoides* Schm., *Rufloria synensis* (Zal.) S. Meyen, *Rhyphidopteris* cf. *praecursoria* S. Meyen, *Nucicarpus piniformis* Neub., and others were determined.

The Tatarian age of the Shadrovskii Formation is confirmed by paleomagnetic data (Gurevich and Slautsitais, 1984).

The Permian section of this zone ends with *the lower Admiralty Subformation* (P_2–T_1ad) represented by a rhythmic alternation of gray sandstones, comprising close to half of all rocks, and red or green siltstones and mudstones whose color is a characteristic feature of the whole formation. Intercalations of tuffaceous rocks are common. Sandstones sometimes grade into gravelstones made up of rounded chert grains as large as 1 cm.

The thickness of the lower subformation is 240 m. Rare bivalves are so poorly preserved that their determinations are hardly valid.

According to paleomagnetic data, the boundary between the Permian and Triassic lies 40–80 m below the subformation top.

Sections of the second type occupied most of the South Island in the early Permian, and extended along the western coast of the North Island and the Admiralty Peninsula, whereas in the late Permian, they resided only in those parts of the South Island where the best-studied sections are located (Figs. 2 and 3).

Lower Permian deposits were formed on a basin slope. The deposits are subdivided into the Kazarka Formation (only the upper part of the upper subformation can be referred to the Permian) and the Moller Formation.

The stratotype of *the Kazarka Formation* is distinguished near the Margantsevyi Stream; earlier this part of the section was assigned to the lower part of the Sokolov Formation (Voyakovskii, 1988). The formation is studied in detail, as it contains numerous beds of manganese ore (Platonov *et al.*, 1992). The upper subformation of Late Carboniferous–Asselian age is composed of black, often siliceous mudstones and siltstones alternating with ore rhodochrosite and siliceous-rhodochrosite rocks. By the number of ore interbeds and their relation to enclosing rocks, the section of the subformation is subdivided into four members, whose thickness varies from 3 to 35 m. The total thickness of the subformation ranges from 20 to 160 m, the Permian deposits accounting for about a half. Goniatite *Parashumardites* sp. typical of the Kasimovian Stage (according to M.F. Bogoslovskaya inferrence), and the Asselian conodonts *Streptognathodus constrictus* Chern. et Resh., *St. wabaunsensis* Gunnell, *Neogondolella dentiseparata* Chern. et Resh., and others (deter-

minations of N.N.Sobolev) were found in different sections of the subformation.

The Moller Formation, which has a stratotype at the Margantsevyi Stream, was earlier distinguished as the upper part of the Sokolov Formation. The formation composition is uniform over most of the area. It is made up of mudstones, and silty mudstones, siltstones with rare interbeds of mixtites and phosphate-bearing mudstones with numerous siliceous-rhodochrositic, calcareous-phosphatic, and other nodules. Numerous limestone olistoliths with diverse Carboniferous fauna occur at several levels. In the eastern flank of the South–Novaya Zemlya anticlinorium, the Moller Formation comprises members and strata of polymictic sandstones, from which its section attains a more complex structure, and thickness abruptly increases from 60 m in the northwest to 240 m in the Severnaya Tainaya River basin. Foraminifers *Protonodosaria* cf. *proceraformis* Gerke, *P. rauserae* Gerke, *Nodosaria krotovi* Tscherd. and other Sakmarian–Artinskian forms are found at the base of the formation, whereas *Nodosaria falcata* Igonin, *N. ustritskyi* Sossip., *Rectoglandulina beringi* A.M.-Maclay, and other forms, which indicate the Kungurian age of enclosing rocks, are encountered at the top.

At the beginning of the Late Permian, the depositional environment changed drastically: extremely high-rate, avalanch sedimentation set in, and as a result, a sequence more than 4 km thick accumulated during the Late Permian. The sequence was studied in detail and subdivided into the Krotov, Litke, Listvenichnaya, Kocherga, Gerke, Savin and Valentina formations. The first three formations corresponding to the Belushii Formation and characterized by the predominance of sandstones and the presence of olistostromes are united into the Karmakul Group.

The Krotov Formation (P_2kr) represents a macrorhythmic alternation of sandstones, siltstones and mudstones, with rare members of mixtites and numerous carbonate and phosphate-carbonate nodules. Spongolith interbeds are also observed.

The formation thickness varied from 625 m in the west to 1000 m in the east.

Foraminifers *Nodosaria lata* Sossip., *N. hexagona* Tscherd., *Rectoglandulina* cf. *beringi* A.M.-Maclay, and other forms are found at several levels, whereas the flora of the Pechora assemblage with *Viatscheslaviophyllum* cf. *vorcutensis* Neub., *Cordaites* aff. *singularis* (Neub.) S. Meyen., *Phylladoderma* aff. *arberi* Zal., *Nucicarpus piniformis* Neub., and other forms is encountered at the formation top. The formation is dated to the Ufimian.

The Litke Formation (P_2lt) represents a giant olistostrome, the characteristic body easily detectable due to numerous landslides, which were described in a special paper (Povysheva and Ustritskii, 1988). Mixtites with separated or numerous olistoliths have a dominant role in the formation. The Permian terrigenous rocks prevail in olistoliths, whereas the Carboniferous and Devonian sandstones are rare. The amount of detritus and lumps in olistostromes is unequal: from individual pieces to conglomerate-like segregations. Olistostromes represent accumulations of fragments of strata and members of rocks, or sheets and blocks with preserved layering, oddly deformed and corrugated, twisted to spiral forms, which occur among the unlayered structureless matrix.

The thickness of such structureless members is up to 150 m. Among these members, the normal layered members of alternating sandstones and siltstones are encountered, being especially numerous in the middle part of the formation.

The thickness of the formation ranges from 900 to 1150 m. Fauna is rare, and attempts to figure out if it occurs *in situ* or redeposited are not necessarily successful. Foraminifers *Rectoglandulina pseudoborealis* Gerke, *Lingulonodosaria clavata* Paalzov, *Frondicularia tsaregradskyi* A.M.-Maclay, and other forms are present in calcareous lenses and nodules. Brachiopods are represented by *Megousia* cf. *kulikii* Fred., *M.* cf. *aagardi* Toula, *Jakovlevia mammatiformis* Fred., and other forms. The combination of brachiopods and foraminifers is typical of deposits, which are referred in the Arctic regions to marine analogues of the Ufimian Stage.

The Listvenichnaya Formation (P_2ls) is composed of alternating massive fine-to-medium-grained polymictic sandstones and members of sandstones alternating with siltstones and mudstones. The amount of sandstones in sections varies from 60 to 80%. Members of uniform siltstones, mudstones and mixtites are individual, and olistostromes are absent. Laminated structures dominate. Siderite develops in the cement of sandstones and in nodules and lenses. Horizons of carbonate and phosphate-carbonate nodules are found in the upper part of the formation. The thickness of the formation is 500–800 m. The stratotype of the formation, like that of the previous formation, is distinguished in the Litke anticline, the Listvenichnaya River basin.

By the position in the section and by rare findings of foraminifers *Saccammina duplexa* Sossip., *Ammodiscus septentrionalis* Gerke, *Nodosaria* cf. *permiana* Tscherd., *Protonodosaria* sp., and other forms, and by bivalves *Atomodesma* cf. *permiana* Newell., the formation was also assigned to the Ufimian Stage.

The Kocherga Formation (P_2kč) is composed of massive and layered mudstones and siltstones with frequent thin interlayers (2–50 cm thick) of calcareous siltstones and, more rarely, pelitomorphic clayey limestones. In the southern part of the zone, the section comprises thick members of mixtites with diverse olistoliths, as well as the Carboniferous organogenic limestones. The thickness of the formation varies from 700 m in southern sections comprising the wildflysch facies to 200 m in northern sections made up of clayey

turbidites. The type section of the Kocherga Formation was described along the Verkhnyaya Butakova River.

Fossils are mainly found in the upper half of the section. Bogoslovskaya (1982) described from this section *Daubichites butakovensis* Bogosl. and *Sverdrupites harkeri* Ruzh., typical of the Roadian Stage of North America. The foraminifer assemblage includes *Nodosaria incelebrata* Gerke, *N. krotovi* Tscherd., *Pseudonodosaria nodosariaformis* K.M.-Maclay, *Rectoglandulina beringi* A.M.-Maclay, *Frondicularia hemiinflata* Gerke, and others. Several brachiopods *Attenuatella stringocephaloides* (*Tschern.* et Lich.) common for deep-water deposits are found. The Kocherga Formation is of the Ufimian age.

The Gerke Formation (P_2gr) is composed of shallow-water marine deposits: calcareous sandstones and siltstones, mudstones with carbonate nodules and lenses with abundant fauna, and horizons of synsedimentary conglomerates in the lower part of the section. Some sections consist of three rhythms from 25 to 80 m thick each. A rhythm begins with a member of massive sandstones (0.5–7 m), which is overlain by a member of bedded siltstones (10–25 m) with thin interlayers (0.1–0.2 m) of calcareous siltstones and clayey limestones, and ends with a member of massive mudstones or clayey siltstones (10–45 m). The thickness of the formation varies within 400–600 m. The type section was described along the Verkhnyaya Butakova River.

Diverse fossils occur throughout the entire formation. Complete lists of fossils are presented in *Permian Deposits of Novaya Zemlya* (1981). Ammonoidea *Daubichites butakovensis* Bogosl., *Sverdrupites amundseni* Nass. and *Altudoceras boreum* Bogosl. are found and described (Bogoslovskaya *et al.*, 1982). Described among foraminifers are *Geinitzina kazanica* K.M.-Maclay, *Nodosaria lata* Sossip., *N. ustritskii* Sossip., *N. fragilis* Tscherd., *Rectoglandulina borealis* Gerke, *Frondicularia bajkurica* Sossip., *F. longissima* K.M.-Maclay, and others. Brachiopods *Grumantia* ex. gr. *kempei* And., *Bathymyonia payeri* Toula, *Stropalosia multiberculata* Ustr., *Megousia weyprechti* Toula, *Yakovlevia impressa* Wiman, *Krotovia licharewi* Freb., *Neoospirifer striatoparadoxus* Toula, and *Spiriferella keilhavii* Buch. are abundant. The appearance of representatives of the genera *Tarrakea* (*T. plana* Ustr.) is very characteristic. The brachiopod assemblage is typical of the upper part of the Starostin Cape Formation on Spitsbergen.

Morozova and Kruchinina (1986) described more than 20 species of bryozoans, mainly new species, from the Gerke Formation. Like the brachiopod assemblage, this association is similar to that from the Starostin Cape Formation on Spitsbergen.

In compliance with data on other fauna groups, Morozova assigns this association to the Ufimian Stage.

The Savin Formation (P_2sv) is composed of marine shallow-water deposits. It is represented by members of laminated calcareous sandstones, siltstones, and mudstones rhythmically alternating with members of monotonous siltstones. The thickness of the first members decreases upsection from 100 to 15 m. The amount of sandstones varies from 60–70% in the south of the facial zone to 40–50% in the north. There are numerous intercalations and lenses of limestones with rich marine fauna.

The thickness of the formation is 500–600 m. The type section was described from the basin of the lower course of the Savin River. The fauna is represented by rich assemblages of foraminifers, brachiopods, bivalves, and bryozoans. The foraminifer and brachiopod assemblages from the lower part of the formation do not differ from those of the Gerke Formation, and this part of the section is still referred to the Ufimian Stage.

An essential renewal of the fauna is observed in the middle part of the formation. Foraminifers *Nodosaria* cf. *hexagona* K.M.-Maclay, *N.* cf. *permiana* Tscherd., *Rectoglandulina beringi* A.M.-Maclay, and other species appear. Among brachiopods, the genera *Spitzbergenia* (*Sp. loveni* Wiman, *Sp. alferovi* Milor.), as well as *Terrakea (?) magna* Sol., *Anemonaria spitzbergiana* Toula, *Bathymyonia* cf. *nevadensis* Meek, *Burovia* cf. *selanderensis* Ustr., *Anidanthus* aff. *rugosus* Lich., and others appear. Among bivalves, *Aviculopecten talis* Lutk. et Lob., *Cyrtorostra laticostata* Netsch., *Glyptoleda coleyi* Fletch., and others are defined. On the basis of this fauna, the age of the upper half of the Savin Formation is determined as Kazanian.

The Valentin Formation (P_2vl) is exposed in the eastern part of the zone, where it occurs in synclines of the Savin and Abrosimov River basins. The formation is composed of members of uniform mudstones and siltstones, usually unstratified. Large nodules of clayey pelitomorphic limestones are common, in which foraminifers *Nodosaria tereta* Crespin, *N.* cf. *hexagona* Tscherd., *Rectoglandulina beringi* A.M.-Maclay, and others, as well as brachiopods *Svalbardia capitolina* Toula, *Krotovia licharewi* Freb., *Anidanthus rugosus* Lich., *Cancrinella* cf. *cancrini* Vern., *Jakovlevia mammatiformis* Fred., *Anemonaria spitzbergiana* Toula, and *Strophalosia morrisiana* King are found. The discovered single specimen of the genus *Compressoproductus*, which is common for the upper Permian deposits of the Tethys, is of particular interest. The thickness of the formation is 300–350 m. The type section was described from the right tributary of the Savin River. The Valentin Formation is dated to the Kazanian.

Sections of the third type are characteristic of the northeastern part of the South Island and the southeastern part of the North Island (up to the Medvezhii Bay). This type of the section is represented by thin and fine-grained varieties of terrigenous, and to a smaller extent, carbonaceous-terrigenous rocks mainly of hemipelagic facies almost free of the benthic fauna. The Lower Permian deposits are subdivided into three formations:

Stepovoi, Tolbei-Yakha and Krasnaya. Formations of the Upper Permian deposits are the same as in previous zones; distinctions available are pointed out in the text.

The Stepovoi Formation (C_2–P_1st), presumably of middle Carboniferous–Early Permian age, is composed of uniform mudstones with interbeds of siliceous mudstones, siliceous rocks, calcareous sandstones and siltstones. Conodonts *Streptognathodus* aff. *wabaunsensis* Gunnell, *S. invaginatus* Chern. et Resh., common for the Asselian Stage, are found in the upper member of uniform dark-gray mudstones. The thickness of the formation is 250–300 m.

The Tolbei-Yakha Formation (P_1tl), like the Stepovoi Formation, is well exposed and studied at limbs of the Litke anticline. It is poorly exposed at the southeastern pericline and the eastern limb of the anticlinorium of the North Island. The type section was described in the Litke anticline in the upper course of the Tavayakha River. The formation is composed of mudstones, siliceous mudstones, calcareous obliquely laminated siltstones and fine-grained quartzitic sandstones. North of the stratotype region, the formation bears a flyschoid aspect, because rhythmic members of silty-siliceous-clayey turbidites prevail in its structure.

The thickness of the formation decreases northward from 200 to 10 m.

The late Artinskian conodonts *Neostreptognathodus exculptus* Igo, *N. pequopensis* Bender, *N. foliatus* Igo, *Neogondolella bisseli* (Clark et Behnken), and *N. intermedia* (Clark et Behnken) are found at the base of the section. Foraminifers *Protonodosaria parviformis* Gerke, *Nodosaria galinae* Gerke et Kar., *N.* cf. *longissima* Sul., *Frondicularia amygdaleformis* Gerke, and *F.* cf. *dilemma* Gerke, characteristic of the uppermost Lower–lowermost Upper (?) Permian units, are observed in the upper part of the section. Redeposited foraminifers of early Bashkirian age occur in calcarenite interbeds. The Tolbei-Yakha Formation is dated to the Early Permian (within the terminal Asselian–Artinskian).

The Krasnaya Formation (P_1krc) with the type section on the left tributary of the Krasnaya River is composed of monotonous deep-water black and dark-gray mudstones with horizons of clayey-siliceous-carbonate concretions and rare and thin interbeds of siltstones or poorly sorted, sometimes calcareous sandstones. The latter are confined to the upper part of the formation. Northward, interbeds of polimictic sandstones wedge out, giving way to lenses and intercalations of quartzitic sandstones. Some members of uniform mudstones are replaced by clayey turbidites in the same direction. The thickness of the formation decreases from 1100 to 800 m also northward. Fossils are very rare. Solitary foraminifers *Protonodosaria* sp. and *Frondicularia* cf. *prima* Gerke suggest that the age of the formation is not younger than the late Artinskian. The Krasnaya Formation is conventionally assigned to the Kungurian.

The Upper Permian deposits are subdivided into the same formations as in the previous type of the section. Distinctive features are the decreasing number and thickness of mixtite members, the prevalence of rhythmic sandy turbidites in the section, and a complete disappearance of fauna. The section ends with the Listvenichaya Formation in the eastern part of the zone. In the western part, near Sukhoi Nos Cape, there are higher horizons which are poorly outcroped; thus, the attempt to compile a section has not yet been successful.

Sections of the fourth type are typical of the middle part of the North Island of Novaya Zemlya (Figs. 2 and 3). In the east, deposits are represented by deep-water, almost fossil-free facies, mainly by clayey turbidites. The section ends here with the lowermost Upper Permian units. In the course of the geological survey, it was subdivided into the Medvezhii, Tsivolki and Krasnaya formations, and its Murmansk sequence was assigned to the lowermost Upper Permian.

The Medvezhii Formation (C_3–P_1md) is composed of mudstones, siliceous mudstones with interlayers of siliceous rocks, and obliquely laminated quartzitic siltstones. In the northern part of the zone, the section comprises concretions and lenslike intercalations of ferruginous-manganese rocks, as well as olistostrome bodies 3–60 m long with olistoliths of limestones, sandstones, and mudstones in a sandy-clayey matrix. The thickness of the formation increases from 70 m near the Medvezhii Bay, where its stratotype was described, to 1300 m near the Sporyi Navolok Cape (Fig. 4, column IVa). Only redeposited foraminifers *Archaediscus* sp., *Endothyra* sp., and *Protonodosaria* sp. are found in the middle part of the formation.

As the Medvezhii Formation is underlain by deposits with the Gzhelian conodonts, it is dated to the Late Carboniferous–Earliest Permian.

The Tsivolko Formation (P_1čv) is made up of members of massive quartzitic and quartzitelike sandstones alternating with mudstones. The origin of these sandstones is related to the rewashing of terrigenous material by contour currents running along slopes. The stratotype of the formation is described from the southern shore of the Tsivolko Bay. The thickness of the formation increases from 30–50 to 300 m northwards. The sand content in the section also increases in the same direction, and intercalations of quartzitic gritstones up to 0.5 m thick appear in the upper part of the section. The formation bears foraminifer *Hemigordius* cf. *schlumbergeri* Howchin only. By correlation with the Tolbei-Yakha Formation of the previous zone, the Tsivolko Formation is arbitrarily assigned to the Artinskian Stage of the lower Permian.

The Krasnaya Formation (P_1krč) is conventionally attributed to the Kungurian Stage. It is made up of members of massive mudstones with rare carbonate and phosphate-carbonate concretions alternating with members of clayey turbidites. The visible thickness of the formation is 600–800 m. Fossils were not found.

The Upper Permian deposits are developed only in the western part of the zone, on the Admiralty Peninsula. *The Murmansk Sequence* (P_2mr), thick, poorly exposed, poorly studied, and composed mainly of monotonous clayey turbidites, is referred to the lowermost Upper Permian. The middle part of the sequence comprises mainly massive or bedded siltstones with members of mixtites, including olistoliths of sandstones and black limestones, which allows a subdivision of the sequence into three units.

The total thickness is 1500–1600 m.

Only *Inoceramus*-like bivalves *Atomodesma* cf. *permiana* New. were found here, which suggest the Late Permian age of the sequence.

During the survey, the overlying deposits, known to be of the Late Permian age, were subdivided according to a scheme adopted for the first zone (Fig. 4), although they bear some peculiarities. The deposits were described by Ustritskii (1984). It should be noted that the Shadrovskii Formation differs from the stratotype in the absence of flora, bar sandstones, and brachiopods; only bivalves are abundant, and Ustritskii suggested to name this part as the Siren sequence. Bivalves *Claraia* and foraminifers *Recurvoides*, common for the Triassic, but also occurring together with the typical Kazanian assemblage of other bivalves, were found at the top of the formation.

There are three members of basaltic tuff at the boundary between the Shadrovskii and Admiralty formations. The Admiralty Formation is little different from that described in the first type of sections.

Sections of the fifth type are typical of the northern margins of Novaya Zemlya (Figs. 2 and 3). This region is separated from the remainder of Novaya Zemlya by a major tectonic deformation, probably by an overthrust of northern orientation. On the eastern coast, near the Sporyi Navolok Cape, anhydrites with Asselian conodonts and Lower Permian olistostromes of the Medvezhii Formation are brought closer together due to this overthrust.

The Upper Paleozoic deposits here, unlike those occupying other regions of Novaya Zemlya, are more shallow-water and distinct because of the quartz-carbonate composition and presence of the benthic fauna (Matveev *et al.*, 1989). In 1939, Likharev and Einor described a rich collection of brachiopods from this block. However, most of the brachiopods are derived from Middle and Upper Carboniferous deposits.

Originally, only the upper part of *the Eks Formation* ($P_{1-2}ex$) with the stratotype on the northern coast of the Eks Bay was assigned to the Permian (Korago and Kovaleva, 1990).

Later, when surveying (scale 1 : 200000) and mapping, the extent of the Eks Formation was reduced to the extent of its upper part assigned to the Permian.

The composition of the formation is uniform. It is represented by black siltstones and mudstones alternating with reddish-brown, horizontally and obliquely bedded quartzitic sandstones. There are several interbeds of fine-pebbled quartz conglomerates. Lenses (?) of anhydrites up to 12 m thick, comprising the Asselian conodonts, occur south of the basic section.

The thickness of the formation is about 600 m. Despite the modest thickness as compared to that typical of Novaya Zemlya, the formation comprises almost a complete Permian interval.

The Asselian–Sakmarian foraminifers *Protonodosaria rauserae* Gerke, *Pr. proceraformis* Gerke, and *Hemigordius ovatusminima* Grozd., and brachiopods *Waagenoconcha humboldti* Orb., *Jacutoproductus protoverchejanicus* Kasch., *Spirifella praesaranae* Step., and *Rhynchopora nikitini* Tschern. were found at the base of the formation.

Megousia weyprechti Toula and *Strophalosia multituberculata* Ustr. typical of the Shadrovskii Formation of the South Island, i.e., of the Kazanian–Tatarian (or Tatarian?) deposits, occur 180 m below the formation top.

According to data of V.P. Matveev, on the western coast of the North Island, only the lower part of the Eks Formation, not younger than the Sakmarian or Artinskian stages, survived the erosion.

CONCLUSION

Based on the foregoing, the Permian deposits of Novaya Zemlya differ greatly from the synchronous deposits of the Uralian foredeep.

Principal distinctions are as follow:

(1) The Uralian foredeep was filled in with terrigenous material derived from the east (the Urals), whereas on Novaya Zemlya, the terrigenous material arrived from the south, from the same Uralian orogen, and to a lesser extent, from the northern uplifts located near the Zhelanie Cape. We did not detect any sign of inflow from the east, and therefore the Uralian orogen did not extended northwards through the Kara Sea, as some researchers believed.

(2) Most of the sections in Novaya Zemlya are made up of deep-water deposits almost free of benthic fauna (Povysheva and Ustritskii, 1988). Shallow-water deposits occur only in the north and south, being the Late Permian in the latter area. A lateral succession of formations in Novaya Zemlya (olistostromes ("wild flysch")–sandy turbidites (or flysch)–clayey turbidites) is typical of passive continental margins of modern oceans.

(3) The youngest marine or, more precisely, lagoonal deposits of the Uralian foredeep are referred to the beginning of the Late Permian (the Solikamsk Horizon), whereas in Novaya Zemlya the marine conditions stood up longer, until the end of the Permian. The availability of paralic and shallow-water marine deposits containing both flora and rich assemblages of all groups of the marine fauna, including ammonoids in southern Novaya Zemlya, makes this region unique for

elaborating the stage (or regiostage) scheme of the Upper Permian for marine deposits of the Boreal realm (Ustritskii, 1982).

Reviewer A.S. Alekseev

REFERENCES

Alferov, B.A., Geological Prospecting in the Vicinity of Kostin Shar (Southern Island of Novaya Zemlya), *Tr. Arkt. Antarkt. Nauch.-Issled. Inst.*, 1935, vol. 26.

Bogoslovskaya, M.F., Ustritskii, V.I., and Chernyak, G.E., Permian Ammonoids of Novaya Zemlya, *Paleontol. Zh.*, 1982, no. 4, pp. 58–67.

Geologiya Sovetskoi Arktiki (Geology of the Soviet Arctic Regions), *Tr. Nauch.-Issled. Inst. Geol. Arktiki*, 1957, vol. 81.

Geologiya SSSR. T. 26. Ostrova Sovetskoi Arktiki (Geology of the USSR, vol. 26: Islands of the Soviet Arctic Regions), Moscow: Nedra, 1970.

Gurevich, E.L. and Slautsitais, I.P., Paleomagnetic Record of the Upper Permian and Triassic Deposits of Novaya Zemlya, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1984, no. 10, pp. 42–50.

Korago, E.A. and Kovaleva, G.N., New Type of the Upper Paleozoic Deposits in Northeastern Novaya Zemlya, *Dokl. Akad. Nauk SSSR*, 1990, vol. 311, no. 4, pp. 932–935.

Matveev, V.P., Sobolev, N.N., Ustritskii, V.I., and Chernyak, G.E., Carboniferous and Permian Deposits Near Ledyanaya Gavan (North Island, Novaya Zemlya), in *Stratigrafiya i paleontologiya paleozoya Sovetskoi Arktiki* (Paleozoic Stratigraphy and Paleontology of Soviet Arctic Regions), Leningrad: Sevmorgeologiya, 1989, pp. 32–42.

Miloradovich, B.V., The Lower Permian Fauna of the Mezhdusharskii Island (South Island, Novaya Zemlya), *Tr. Arkt.-Antarkt. Nauch.-Issled. Inst.*, 1936, vol. 37, pp. 37–82.

Miloradovich, B.V., Geological Synopsis of the Northeastern Coast of the North Island, Novaya Zemlya, *Tr. Arkt.-Antarkt. Nauch.-Issled. Inst.*, 1936a, vol. 38, pp. 51–122.

Morozova, I.P. and Kruchinina, O.N., *Permskie mshanki Arktiki* (Permian Bryozoans of the Arctic Regions), Moscow: Nauka, 1986.

Permskie otlozheniya Novoi Zemli (Permian Deposits of Novaya Zemlya), Leningrad: Nauka, 1981.

Petrenko, A.A., Materials on the Geology of the Western Coast of Novaya Zemlya between Matochkin Shar and Domashnyaya Guba, *Tr. Arkt.-Antarkt. Nauch.-Issled. Inst.*, 1936, vol. 57, pp. 7–168.

Platonov, E.G., Povysheva, L.G., and Ustritskii, V.I., Genesis of Carbonate Manganese Ore of the Pai-Khoi–Novaya Zemlya Region, *Litol. Polez. Iskop.*, 1992, no. 4, pp. 76–89.

Povysheva, L.G. and Ustritskii, V.I., Facial Zonation in Upper Permian Deposits of Novaya Zemlya, *Litol. Polezn. Iskop.*, 1988, no. 4, pp. 105–111.

Rysyukov, I.L., Geological Structure of the Western Coast of South Island, Novaya Zemlya, from Belush'ya Guba to Domashnyaya Gyba, *Tr. Arkt.-Antarkt. Nauch.-Issled. Inst.*, 1936, vol. 57, pp. 154–169.

Ustritskii, V.I., The Novozemelian Stage of the Upper Permian, *Geologiya Yuzhnogo ostrova Novoi Zemli* (Geology of South Island, Novaya Zemlya), Leningrad: Sevmorgeologiya, 1982, pp. 37–47.

Ustritskii, V.I., Upper Permian Productids of South Island, Novaya Zemlya, *Novaya Zemlya na rannikh etapakh geologicheskogo razvitiya* (Novaya Zemlya at Early Stages of Geological Evolution), Leningrad: Sevmorgeologiya, 1984, pp. 109–121.

Ustritskii, V.I., Triassic and Upper Permian Deposits of the Admiralty Peninsula, Novaya Zemlya, in *Litologiya i paleogeografiya Barentseva i Karskogo morei* (Lithology and Paleogeography of the Barents and Kara Seas), Leningrad: Nauch.-Issled. Inst. Geol. Arktiki, 1981, pp. 55–65.

Voyakovskii, S.K., Manganese-bearing Potential of the Rogachev–North Taininskii Region of Novaya Zemlya, *Litol. Polezn. Iskop.*, 1988, no. 3, pp. 59–69.

Stratigraphy and Geological Correlation, Vol. 4, No. 5, 1996, pp. 450–466. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 5, 1996, pp. 35–52.
Original Russian Text Copyright © 1996 by Kirichkova, Doludenko.
English Translation Copyright © 1996 by МАИК Наука/Interperiodica Publishing (Russia).

New Data on the Jurassic Phytostratigraphy in Kazakhstan

A. I. Kirichkova* and M. P. Doludenko**

** Russian Petroleum Research and Exploration Institute, Liteinyi pr. 39, St. Petersburg, 191104 Russia*
*** Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109107 Russia*

Received October 24, 1994

Abstract—Based on new original paleofloral and stratigraphic data, collected recently from Jurassic sections in southern Kazakhstan, and on a critical revision of available collections and published data on Jurassic continental sequences, a new stratigraphic scheme is suggested for Jurassic coal-bearing deposits of Kazakhstan. Five phytostratigraphic (correlative) assemblages were defined, and provided grounds to correlate sections in different basins and to prove their ages. Comparative analysis of the taphoflora taxonomic composition permitted paleophytogeographic environments in Kazakhstan and their changes with time to be considerably specified. It was established that in the Early to early Middle Jurassic, the majority of Kazakhstan's territory, except its western areas, was occupied by flora of the Siberian type. During the second half of the Middle Jurassic and Late Jurassic, the Siberian flora was replaced by the Euro-Sinian assemblages throughout the region, except in northern Kazakhstan. This was caused by paleogeographic reorganizations that mainly resulted from transgression of the Tethys. The defined patterns in temporal flora distribution provided a reliable criterion for the correlation of coal-bearing deposits and their age determination, as well as for the refinement of phytochoria boundaries.

Key words: *phytostratigraphy, Jurassic deposits, Kazakhstan.*

In Kazakhstan, Jurassic terrestrial deposits are unevenly distributed. They occur in many basins and intermontane depressions varying in thickness and age. The stratigraphy of these coal-bearing deposits has been studied by many researchers (Buvalkin, 1958, 1978; Buvalkin and Soldatova, 1988; Buvalkin *et al.*, 1983, 1989; Sakulina, 1968, 1976; Sevryugin *et al.*, 1989, 1990; Savel'ev *et al.*, 1973; Kirichkova *et al.*, 1989; and others). For every basin, the stratigraphic scheme was elaborated, a detailed lithological description was carried out, and the sequence was subdivided into formations. Still, the dating of units and, moreover, their spatial correlation within separate basins and with units in other basins has remained ambiguous up until the present. This was evident during the 3rd Kazakhstan Stratigraphic Meeting held in 1986 in Alma Ata. Mostly debated at this meeting were problems concerning the age and correlation of Jurassic deposits in every area. Many formations in various basins were found to be untypified and lacking correct paleontological characteristics. Available large paleontological collections were insufficiently coordinated with respect to sections, and plant remains were formally determined. This concerns many basins, such as the Alakol', Maikyuben', Koitas, Turgai, Karaganda, and others.

At the time of the above-mentioned meeting, sections in western Kazakhstan were the best-studied with respect to their phytostratigraphy, whereas the taxonomy of taphoflora[1] was well examined only in Jurassic deposits of the Karatau Range (southern Kazakhstan). At the meeting, however, many drawbacks in stratigraphic interpretations suggested by local geologists for Jurassic sequences of southern Kazakhstan (Buvalkin *et al.*, 1983) were brought to light. Accordingly, we decided together with O.A. Fedorenko and N.N. Sevryugin, geologists from the Yuzhkazgeologiya and palynologist G.V. Sakulina to thoroughly analyze all geological data on Jurassic deposits of southern Kazakhstan, to revise reference and stratotype sections, and to elaborate the stratigraphic scheme with reliable paleobotanic substantiation. The results of the research of the upper Middle–lower Upper Jurassic sequence in the Karatau Range were discussed in several publications (Sevryugin *et al.*, 1989, 1990; Doludenko *et al.*, 1989). The stratigraphic scheme of the Lower–lower Middle Jurassic of southern Kazakhstan was adopted at the meeting unrevised and without the analysis of paleobotanical data.

During field work in 1990, we collected valuable paleofloral and stratigraphic materials from natural outcrops in southern Kazakhstan, where the lower strata of the Jurassic sequence are observed at the day surface. These are the sections in the Lenger coal field, Kel'temashat, and southern Leont'ev depression (the Karatau Range). In addition, we studied cores from several wells that penetrated thick Jurassic deposits in the recently discovered southern Turgai oil-and-gas field. These geological materials, along with paleofloral collections from Jurassic deposits of other basins in Kazakhstan stored at the Institute of Zoology of the

[1] Taphoflora means the particular plant assemblage from the particular locality.

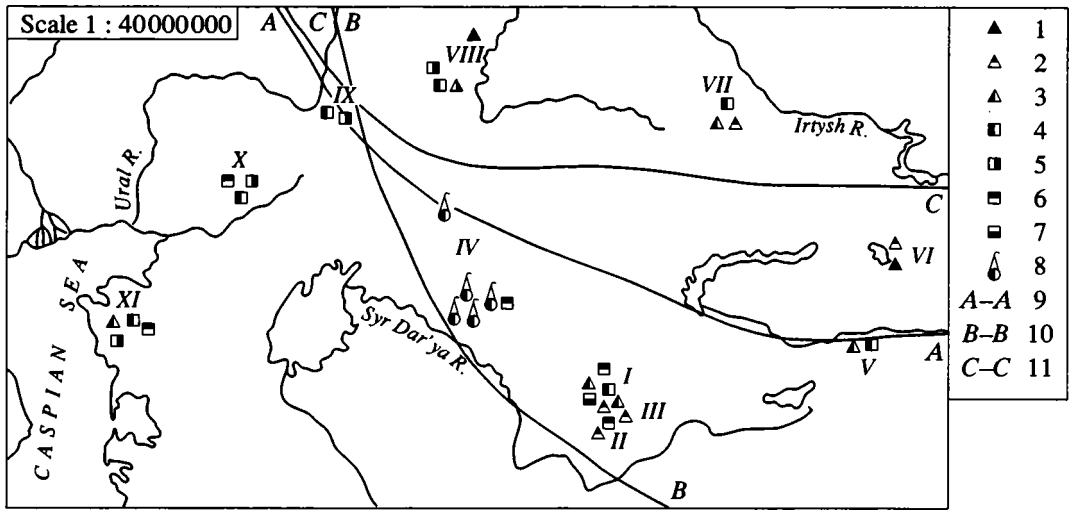


Fig. 1. Localities of Jurassic flora in Kazakhstan basins and paleophytogeographic zonation. (*I*) Leont'ev depression (Karatau Range); (*II*) Lenger depression; (*III*) Kel'temashat depression; (*IV*) southern Turgai depression; (*V*) Ili coal-bearing basin; (*VI*) Alakol' coal deposit; (*VII*) Maikyuben' coal deposit; (*VIII*) northern Turgai depression; (*IX*) Orsk coal-bearing basin; (*X*, *XI*) western Kazakhstan: (*X*) northern Caspian depression; (*XI*) Mangyshlak.

(1–7) Phytostratigraphic complexes: (1) earliest Early Jurassic; (2) middle Early Jurassic, (3) terminal Early Jurassic; (4) earliest Middle Jurassic; (5) mid-Middle Jurassic; (6) latest Middle Jurassic; (7) Late Jurassic; (8) wells; (9–11) boundary between Siberian and Euro-Sinian paleofloral provinces: (9) during the Early–Middle Jurassic, after Vakhrameev, 1988; (10) presumable boundary during the Early–earliest Middle Jurassic; (11) second half of the Middle–earliest Late Jurassic.

Academy of Sciences of Kazakhstan, and published data (Orlovskaya, 1968, 1974, 1977; Doludenko and Orlovskaya, 1976) served as the basis for the elaboration of new views on the age and correlation of Jurassic deposits (Fig. 1).

During the Jurassic, the Kazakhstani territory represented a denudation plain with gradual relief differentiation toward the formation of highlands and intermontanes to piedmont depressions (*Paleogeografiya* ..., 1975; Buvalkin, 1978). Only in western Kazakhstan, the coastal plain with separate hypsometrically higher areas similar to the recent Karatau Range in Mangyshlak existed at that time. However, in the second half of the Jurassic, the coastal plain was gradually covered by sea. The contrast relief forms in the Kazakhstani territory predetermined the evolution of every basin and their diachronous depositional history. Diverse facies and their spatial variability prevent direct correlation of these deposits even in a single basin. The problem of age determination is even more complicated by the biogeographic and landscape differentiation of coenoses, which is natural for such a huge territory as Kazakhstan. Therefore, when studying the stratigraphy of terrestrial sequences based on paleobotanical data, we assumed as particularly important the detailed interpretations of the taxonomic affinity of fossil plant remains in order to use them as possible age indicators.

Because of their completeness, the Jurassic sections of the Leont'ev depression in southern Kazakhstan (the Karatau Range) were adopted at the 2nd Kazakhstan stratigraphic meeting in 1986 as the reference ones. There, the coal-bearing deposits comprise all Jurassic series, and in variable scope they are traced, in addition to the Leont'ev depression, over the Lenger and Kel'temashat coal fields. Within the Jurassic sequence of southern Kazakhstan, we distinguished five phytostratigraphic[2] or correlative[3] assemblages named after Chokpak–Kel'temashat (Early Jurassic), Kurkureu–Boroldai (with two subassemblages of the terminal Early–earliest Middle Jurassic), Borolsai (Middle Jurassic, presumably Bathonian), Ceramic Clay (terminal Middle Jurassic), and Karabastau (Late Jurassic, Oxfordian–Kimmeridgian) localities.

The Chokpak–Kel'temashat phytostratigraphic assemblage (Plate I, *1–10*; Plate II, *1–5*) occurs in coal-bearing deposits of the Chokpak and Kel'temashat coal fields. In the first of them, located in the Chokpak River basin of the southern Karatau Range (Fig. 2; *III*), the 350-m-thick coal-bearing unit rests unconformably upon conglomerates and consists of alternating siltstones, sandstones, claystones, and coal beds (Fig. 2). According to Orlovskaya's (Doludenko and Orlovskaya, 1976) and our data, the complex was collected from the mine wastes northeast of the Chokpak open pit near the Kremnevka Settlement, and from wells drilled in the northwestern flank of the Chokpak coal field (Well 17) and southwest of the latter (Well 15). The impoverished flora from these localities includes, according to Orlovskaya's and our determinations, 27 species (Table 1). The Chokpak taphoflora is dominated by

[2] The term was introduced by Kirichkova, 1982.
[3] The term was introduced by Meyen, 1990.

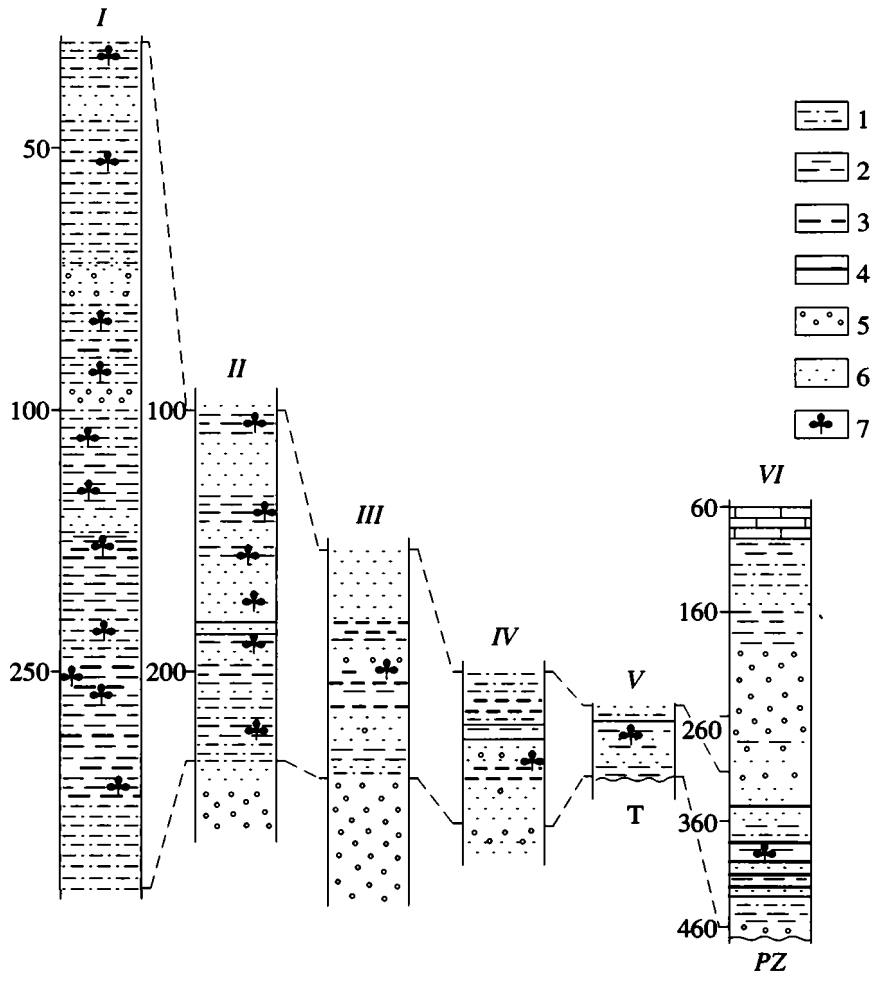


Fig. 2. Distribution of the Chokpak–Kel'temashat correlative plant assemblage in main Lower Jurassic sections of Southern Kazakhstan. *I–IV*, sections in the Chokpak coal deposit area, the Karatau Range (after G.V. Sakulina and N.N. Sevryugin): (*I*) Well 15; (*II*) Well 17; (*III*) outcrop in the Chokpak River valley; (*IV*) Mel'nichnyi area; (*V, VI*) Kel'temashat depression (after N.N. Sevryugin): (*V*) outcrop in the Kel'temashat River basin, (*VI*) Well 6.
(1) Siltstone; (2) clay; (3) coaly clay; (4) coal; (5) conglomerate; (6) sandstone; (7) plant imprints.

ferns of the *Cladophlebis* genus and Czekanowskiales of *Phoenicopsis* and *Czekanowskia* genera represented by local species. Horsetails of the *Neocalamites* genus are also present. Table 1 shows that the floral composition is uniform throughout the Chokpak coal field. From this viewpoint, it is not clear why the plant assemblages reported from the outcrop in the Chokpak River valley and the Mel'nichnyi area of the coal field (Doludenko and Orlovskaya, 1976) were previously considered to be diachronous, i.e., the Early and Middle Jurassic. We collected similar plant assemblages with the predominance of the same *Cladophlebis* and *Czekanowskia* species (Table 1) from the Kel'temashat Formation in the Kel'temashat coal field. This latter is located south of the Chokpak coal field five kilometers southeast of Chimkent. Here, in the left side of the Kel'temashat River (Fig. 1), the member of alternating sandstones, dark-gray and gray clays, and siltstones with total thickness of about 60 m is exposed. The Kel'temashat Formation conformably rests upon weathered Triassic rocks and is overlain by variegated coarse-grained sandstones with clay and conglomerate interbeds (Fig. 2). The formation yielded abundant plant remains confined to gray and dark-gray clays. Previously, in addition to our samples (Table 1), Orlovskaya, who studied the collection of G.B. Sakulina, determined *Equisetites lateralis* (Phill.) Phill. and two species of the *Cladophlebis* genus (*C. argutula* (Heer) Font. and *C. sublobata* Johans.). The analogous plant assemblage, whose species list was never published during Orlovskaya's time, was collected by her from several wells drilled in the Kel'temashat coal field (Table 2). Like the Chokpak taphofloras, this assemblage is dominated by various *Cladophlebis* species and abundant *Czekanowskia* of the *latifolia* group.

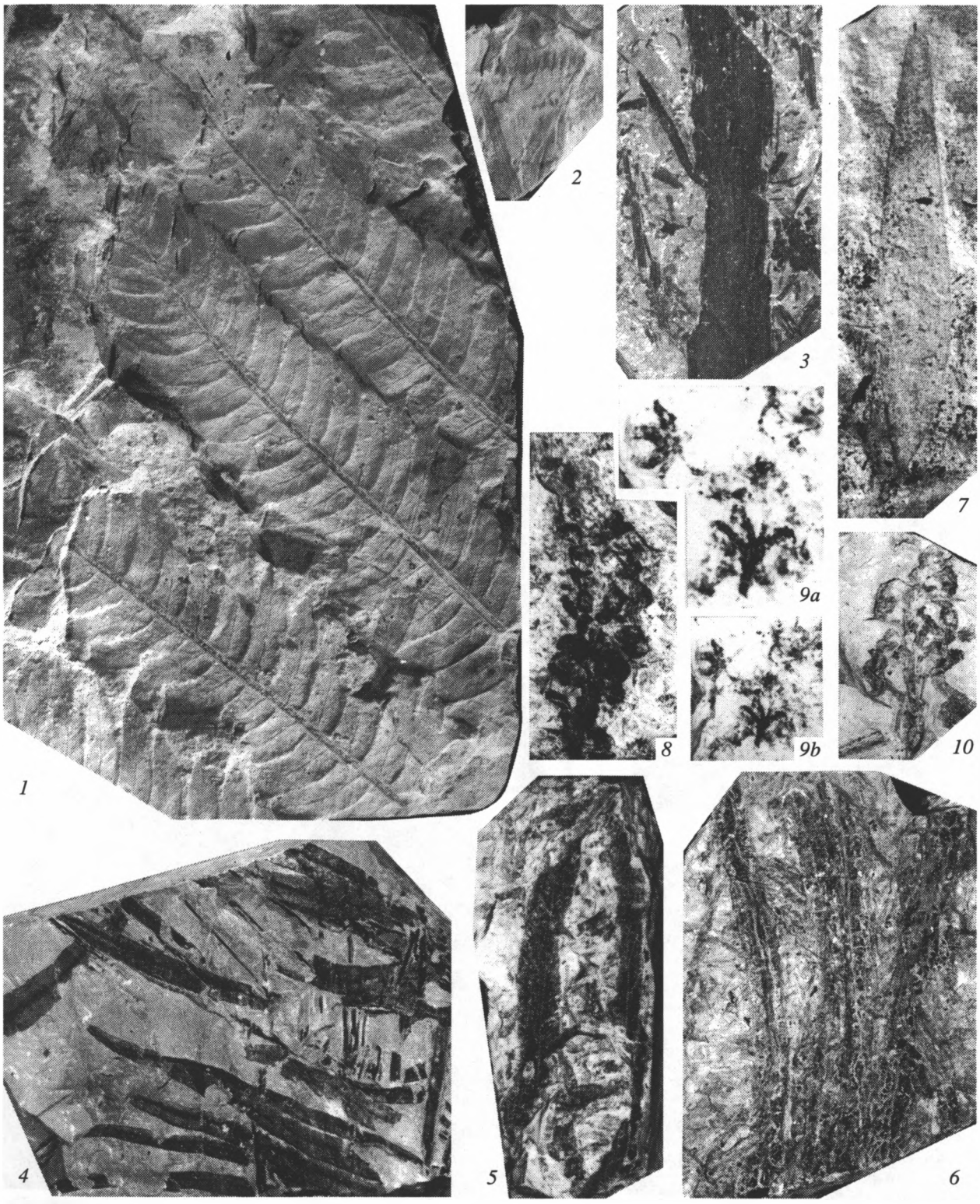


Plate I. The Chokpak–Kel'temashat plant assemblage (all plant images are given in natural size except those specially indicated). (*1*) *Cladophlebis chokpakensis* Orlovsk., fragment of pinnate leaf, specimen 853/70, southern Kazakhstan, Kel'temashat River, trimming trench above the abandoned gallery, the Kel'temashat Formation. (*2*) *Neocalamites* sp., shoot fragment with leaf insertion marks in the node, specimen 853/71, *ibid.* (*3*) *Neocalamites* cf. *carcinoides* Harris, stem fragment with leaf imprints, specimen 853/72, the Karatau Range, the Chokpak coal deposit, coal-bearing unit. (*4*) *Annulariopsis*(?) sp., horsetail leaf remains, specimen 853/73, *ibid.* (*5*, *6*) *Dictyophyllum* sp., imprints of narrow leaf segments with reticular venation, specimens 853/74 and 853/75, southern Kazakhstan, the Kel'temashat River, trimming trench above the abandoned gallery, the Kel'temashat Formation. (*7*) *Ferganiella lanceolata* Brick, isolated leaf, specimen 853/76, *ibid.* (*8*) *Leptostrobus* sp., specimen 853/77, the Karatau Range, the Chokpak coal deposit, the Mel'nichnyi area, coal-bearing unit. (*9a*, *9b*) *Swedenborgia* sp., scale imprints, specimen 853/78 (*9b*, ×2), southern Kazakhstan, Kel'temashat River, trimming trench above the abandoned gallery, the Kel'temashat Formation. (*10*) *Stenorachis* sp., strobilus fragment, specimen 853/79, *ibid.*

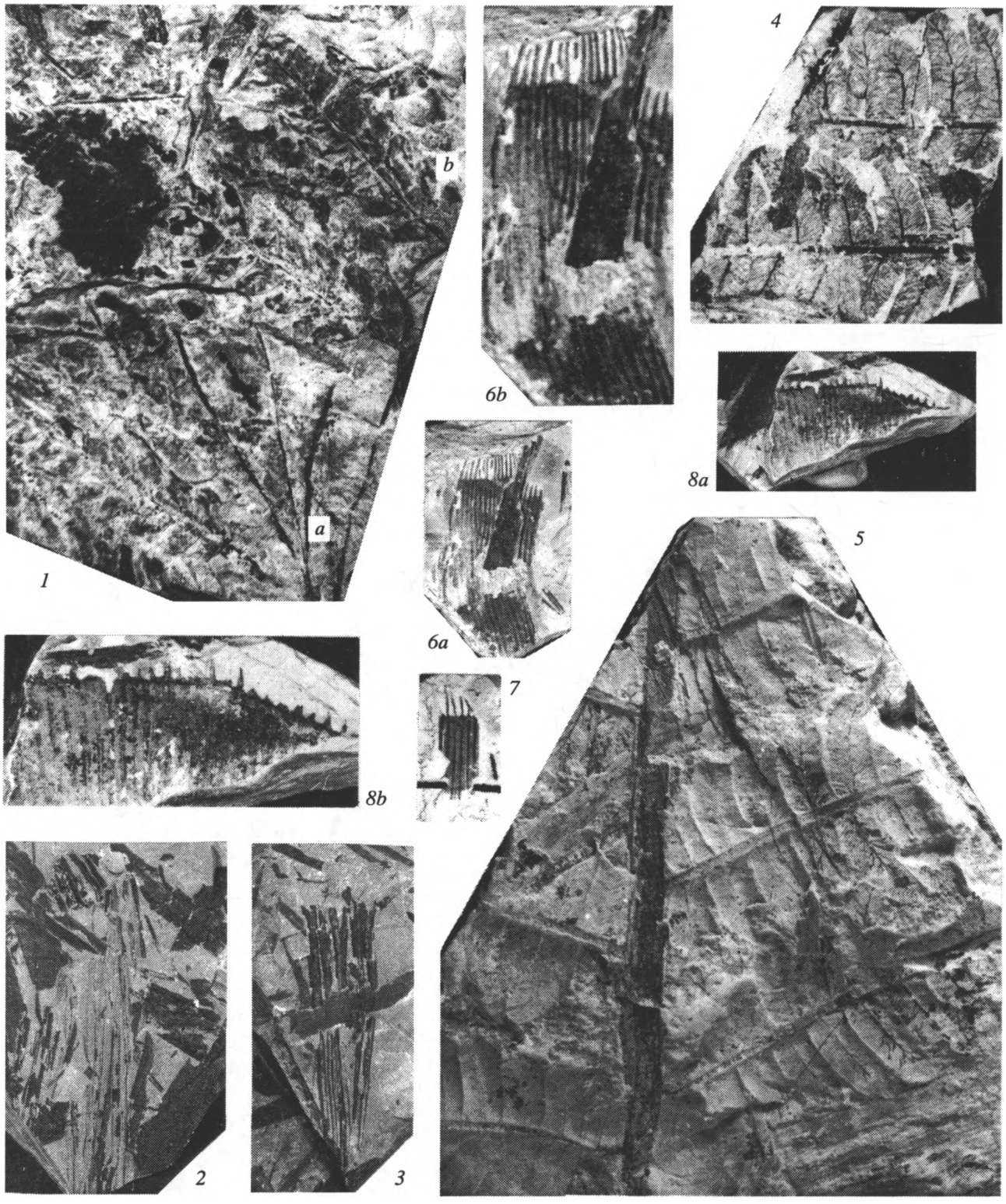


Plate II. (*1–5*) The Chokpak–Kel'temashat assemblage. (*1a*, *2*, *3*) *Czekanowskia australis* Kiritch. et Samyl. (*1b*) *Cladophlebis chokpakensis* Orlovsk., specimens 853/80, 853/81, and 853/82, the Karatau Range, the Chokpak coal deposit, coal-bearing unit. (*4*, *5*) *Cladophlebis haiburnensis* (L. et H.) Sew., fragments of pinnate leaves, specimens 853/83 and 853/84, southern Kazakhstan, Kel'temashat River, trimming trench above the abandoned gallery, the Kel'temashat Formation. (*6–8*) The plant assemblage from the lower Toguz Formation. (*6a*, *6b*, *7*) *Equisetites acmophyllus* Kiritch., stem imprints with leaf whorl, specimens 853/34 and 853/33, the Lenger depression, the Ashchi River, the Toguz Formation (lower portion), (*6b*, ×2; *8a*, *8b*) *Equisetites beani* (Bunb.) Sew., stem fragment with leaves in the node, specimen 853/32, *ibid.*

Table 1. Composition of the Chokpak–Kel'temashat plant assemplage

Species	Well 15			Well 17, 100–200 m	Chokpak coal deposit		Kel'temashat River
	50–100 m	100–200 m	200–280 m		mine wastes	Mel'nichnyi area	
Annulariopsis sp.					+		
Neocalamites cf. *carcinoides* Harris					+		
Equisetites lateralis (Phill.) Phill.				+			
Todites princeps (Presl.) Goth.							+
Cladophlebis denticulata (Brong.) Font.					+	+	
C. haiburnensis (L. et H.) Sew.					+	+	+
C. nebbensis (Brong.) Nath.					+	+	+
C. chokpakensis Orlovsk.					+	+	+
C. witbiensis var. *punctata* Brick					+		
C. suluctensis Brick					+		
C. aktashensis Tur.-Ket.	+						+
C. magnifica Brick						+	
Raphaelia dentata Orlovsk.					+		
Clathropteris obovata Oishi						+	sp.
Dictyophyllum sp.							+
Sphenobaiera sp.		+	+			+	
Ginkgo ex gr. *sibirica* Heer	+			sp.			
Desmiophyllum rarinervis (Krysht. et Pryn.) Kiritch.					+		
Phoenicopsis sakulinae Kiritch.						+	
Ph. sevrjuginii Kiritch.					+		
Ph. ex gr. *angustifolia* Heer		+		+		+	
Czekanowskia asiatica Kiritch. et Samyl.	+						
Cz. australis Kiritch. et Samyl	+				+		
Cz. ex gr. *latifolia* Tur.-Ket		+	+	+		+	+
Cz. ex gr. *rigida* Heer	+	+		+			
Podozamites lanceolatus (L. et H.) Schimp.				+			+
Pityophyllum nordenskioldii (Heer) Nath.	+	+	+	+			
Sorosaccus sibiricus Pryn.					+		
Stenorachis striolatus Heer						+	+

The Early Jurassic age of the Chokpak–Kel'temashat taphofloras is beyond question, which is supported by the complete absence of any Middle Jurassic forms, the *Coniopteris* genus included, and by the prevalence of various *Cladophlebis* species along with *Neocalamites* and *Podozamites* forms. Taxonomically, the Chokpak–Kel'temashat taphofloras correspond to the first evolutionary stage of the Jurassic paleoflora of the Siberian type, which was composed of *Neocalamites, Equisetites, Cladophlebis, Sphenobaiera, Ginkgo, Czekanowskia, Podozamites*, and *Pityophyllum* species in the first half of the Early Jurassic. Flora of a similar type was spread over southern west Siberia and the greater part of Kazakhstan except its western areas. These regions represented a single vegetation zone within the Siberian paleofloral province (Vakhrameev, 1964, 1968; Vakhrameev *et al.*, 1970; Kirichkova *et al.*, 1989, 1992).

In eastern Kazakhstan, taphofloras from the lower Sarykol' Formation of the Maikyuben' area and Uzun-

Table 2. Composition of plant assemblage from the Kel'temashat Formation, the Kel'temashat coal field

Species	Well 6, depth 405 m	Well 23, depth 87–103 m	Well 359, depth 175–234 m
Neocalamites sp.			+
Equisetites ex gr. *beanii* (Bunb.) Sew.			+
Equisetites sp.		+	+
Cladophlebis aktashensis Brick			+
C. haiburnensis (L. et H.) Sew.	+	+	
C. magnigolia Brick			+
C. denticulata (Brongn.) Font.			+
Ginkgo ex gr. *digitata* Heer			+
Sphenobaiera sp.		+	+
Erethmophylum (?) sp.			+
Czekanowskia ex gr. latifolia Tur.-Ket.	+	+	
Posozamites lanceolatus (L. et H.) Schimp.		+	+
Pityophyllum nordenskioldii (Heer) Nath.		+	+
Cycadocarpidium sp.		+	
Samaropsis sp.			+

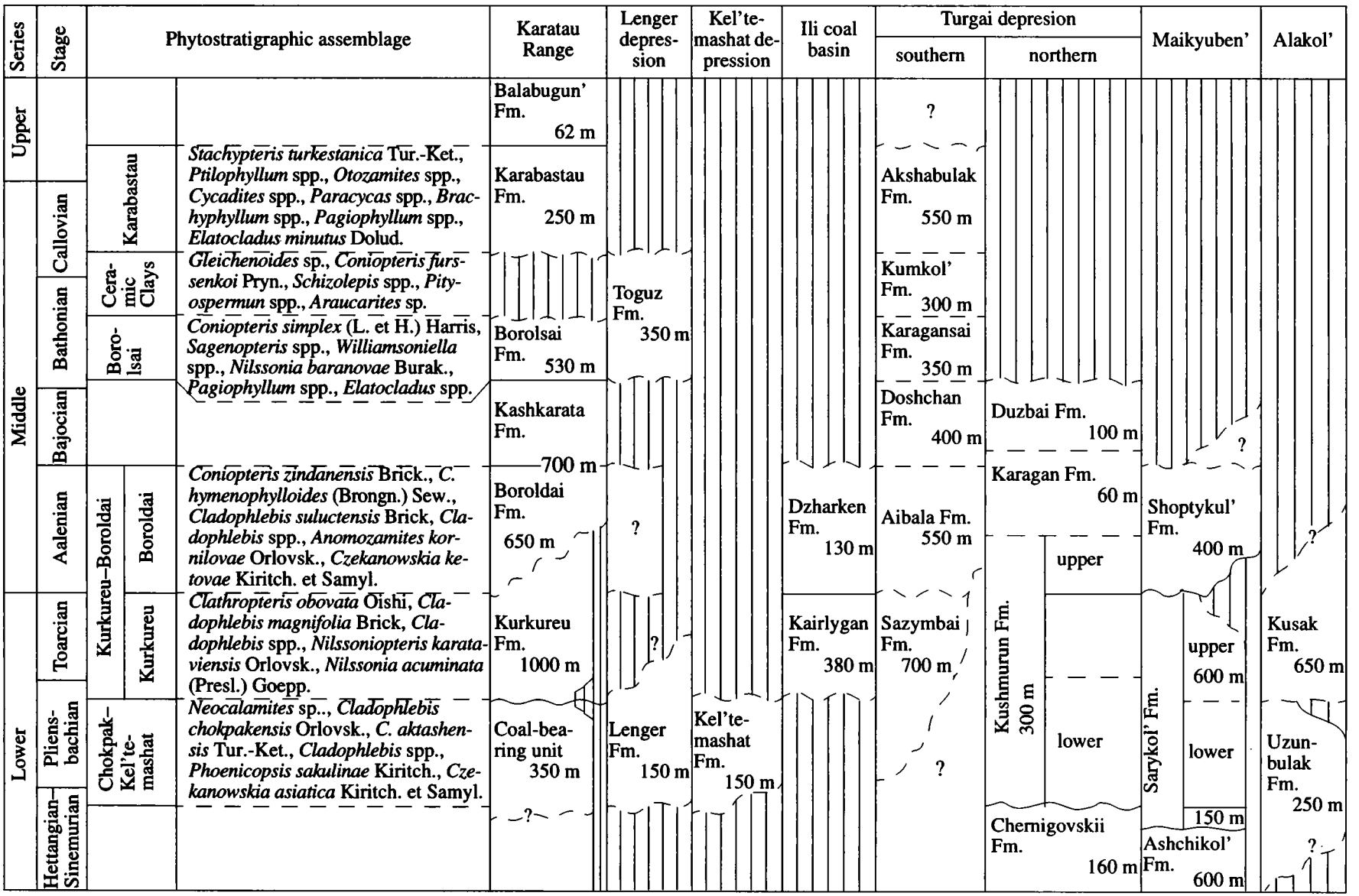
bulak Formation of the Alakul' area (Table 3), which were studied by Orlovskaya (1968), correspond in composition and evolutionary level to the Chokpak–Kel'temashat plant assemblage of southern Kazakhstan. They predominantly consist of the analogous *Cladophlebis* forms occurring together with *Neocalamites, Czekanowskia*, and *Podozamites* species. The age of the Ashchikol' Formation in the Maikyuben' area (Table 3) is likely older. In northern Kazakhstan, Chokpak–Kel'temashat taphofloras can be correlated with those from the lower Kushmurun Formation of the northern Turgai region (Vakhrameev, 1964).

The Kurkureu–Boroldai correlative plant assemblage occurs in reference and stratotype sections of the Kurkureu and Boroldai formations (Fig. 3) of the Leont'ev intermontane depression in southern Kazakhstan (Sevryugin *et al.*, 1989, 1990). Its taxonomic composition was described by Orlovskaya (Doludenko and Orlovskaya, 1976). The assemblage basically consists of various *Cladophlebis* and *Coniopteris* forms, cycadophytes of *Nilssoniopteris*, *Anomozamites*, and *Nilssonia* genera, and *Czekanowskia* and *Phoenicopsis* species. The assemblage is subdivided into the Kurkureu and Boroldai subassemblages differing in diversity of the *Coniopteris* genus. In taphofloras from the Kurkureu Formation (the Kurkureu plant subassemblage, Fig. 3; Doludenko and Orlovskaya, 1976), the share of the *Coniopteris* genus is still insignificant. The leaf remains, rather common in the formation section, are usually confined to its upper portion and cannot be identified at the species level. *Cladophlebis* species and cycadophytes of *Nilssoniopteris*, *Pseudoctenis*, and *Nilssonia* genera are dominant in these taphofloras.

In the Boroldai plant subassemblage characteristic of the Boroldai Formation (Fig. 3) including the same *Cladophlebis* species, the role of the *Coniopteris* genus becomes more important. It undoubtedly includes *C. hymnophylloides* (L. et H.) Sew. and *C. zindanensis* Brick, as well as species of *Anomozamites* and *Nilssonia* genera and several *Nilssoniopteris* forms (Doludenko and Orlovskaya, 1976). Based on the recently accepted concept on the evolution of *Coniopteris* and *Nilssonia* genera at the Early–Middle Jurassic boundary (Vakhrameev *et al.*, 1970; Kirichkova *et al.*, 1992), suggesting their maximum diversity at the beginning of the Middle Jurassic, the Kurkureu plant subassemblage can be dated as the late Early Jurassic, while the Boroldai plant subassemblage with two *Coniopteris* species is likely the early Middle Jurassic in age. Thus, the Early–Middle Jurassic boundary in sequences of the Karatau Range should probably be placed at the base of the Boroldai Formation. In eastern Kazakhstan (Table 3), the Kurkureu taphoflora corresponds to taphofloras from several other units, such as the Kairalgan Formation of the Ili River basin (Buvalkin, 1964; Orlovskaya, 1974), which also include rare undefinable *Coniopteris* species, upper Sarykol' Formation in the Maikyuben' coal field, and Kusak Formation in the Alakol' area (Orlovskaya, 1968). Taphofloras of the Dzharken Formation of the Ili basin the Shoptykul' Formation of the Maikyuben' coal field, which show the first occurrence of several *Coniopteris* species, most likely correlate with the Boroldai assemblage (Table 3). In the northern Turgai depression of northern Kazakhstan, taphofloras from the upper Kushmurun Formation are analogous to the Kurkureu–Boroldai plant assemblage. Moreover, in their composition and diversity, they are closer to floras of the Boroldai plant subassemblage.

The last assemblage was first recorded in wells drilled in the southern Turgai depression. Here, the oil-prospecting wells recently penetrated a thick, up to 3000 m, section of Jurassic terrestrial deposits comprising the lower part of the sedimentary cover and filling local depressions in the pre-Mesozoic basement. Unfortunately, the stratigraphy of these deposits remains ambiguous. In recent publications (Buvalkin *et al.*, 1988, 1989) dealing with geochemical properties of Jurassic oil-bearing deposits in the southern Turgai depression, the considered section was subdivided into the Bektas, Aibola, Doshchan, Karagansai, Kumkol', and Akshabulak formations. However, the cited authors did not define the stratotype sections, intervals in wells, thicknesses, and lithologic characteristics of the formations.

Table 3. Correlation of Jurassic coal-bearing deposits of some Kazakhstan basins with the reference section of the Leont'ev depression (the Karatau Range, Southern Kazakhstan) based on fossil plant remains



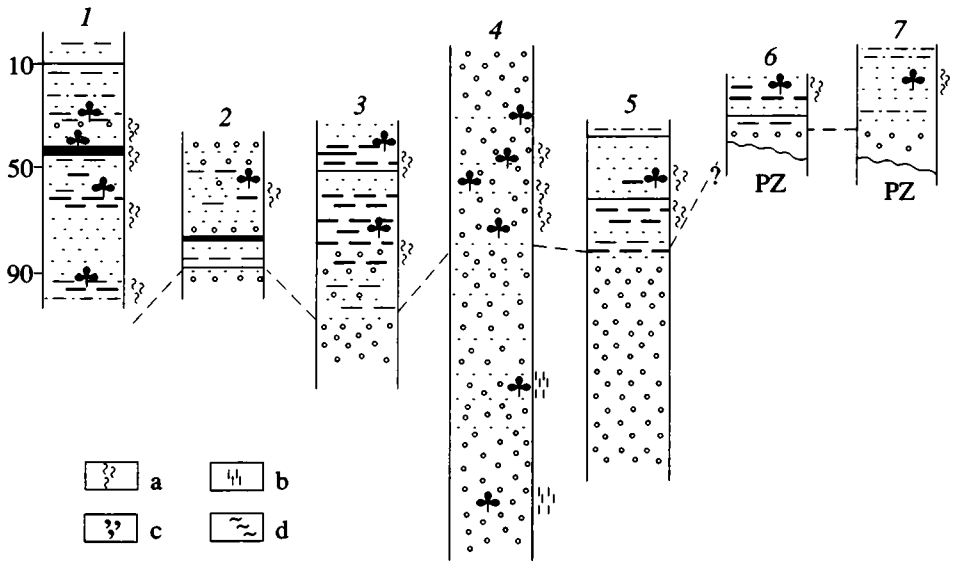


Fig. 3. Distribution of the Kurkureu–Boroldai correlative plant assemblage in main Jurassic sections of the Karatau Range. (*1–3*) Taskomyrsai coal deposit (after G.V. Sakulina and N.N. Sevryugin): (*1*) Well 261; (*2*) outcrop in the Taskomyrsai locality; (*3*) Taskomyrsai coal deposit; (*4*) Kurkureu Sai (stratotype of the Kurkureu Formation, after N.N. Sevryugin); (*5*) Akbet Ravine; (*6*) Boroldai coal deposit (stratotype of the Boroldai Formation); (*7*) Akbulak Balka (after G.V. Sakulina and N.N. Sevryugin). (a) Boroldai plant subassemblage; (b) Kurkureu plant subassemblage; (c) Borolsai plant assemblage; (d) Karabastau plant assemblage. For lithological symbols see Fig. 2.

Moreover, in the stratigraphic scheme presented by Buvalkin at the above-mentioned meeting, the Bektas Formation was renamed without any explanation as the Sarymbai Formation. Therefore, these units are invalid although they were included into the stratigraphic column of the southern Turgai depression as a part of the Jurassic stratigraphic scheme of Kazakhstan adopted in 1986 (Table 3). Later, due to the courtesy of geologists from the Yuzhkazgeologiya, who collaborated with Buvalkin, we obtained core samples with plant remains from the same wells. The plant assemblages from these cores appear to be taxonomically close to those from Jurassic deposits of the Karatau Range. The lower strata of the Jurassic section (the Sarymbai and Aibala formations?) of the southern Turgai depression penetrated by wells in Sazymbai, Aryskum, and Kumkol' areas (Figs. 1 and 4) yielded floral remains similar to the Kurkureu–Boroldai plant assemblage of the Karatau Range (Table 4). According to Buvalkin (1988), this portion of the section (the Aryskum area, Well 15-S, depth interval 1206–1410 m) was referred to the Akshabulak Formation, whose age was determined, based on palynological data, as the Late Jurassic.

The direct correlation of the Kurkureu–Boroldai taphofloras of southern, eastern, and northern Kazakhstan with those from western Kazakhstan, in particular, with taphofloras from the Kokala and Tonasha formations of Mangyshlak (Kirichkova *et al.*, 1989) is impossible because of their distinct taxonomical difference. This is evident from the Euro-Sinian affinity of western Kazakhstan taphofloras (Vakhrameev, 1988; Kirichkova *et al.*, 1989) comprising different characteristic plant groups. Yet, the similar trend in the evolution of individual plant groups at the Early–Middle Jurassic boundary, in particular of *Coniopteris* and *Nilssonia* genera, is observed in the Early–Middle Jurassic taphofloras from southern Russia (North Caucasus), western Kazakhstan and West Siberia (Vakhrameev, 1964, 1969, 1982; Kirichkova *et al.*, 1992). For instance, taphofloras from the upper portion of the Ergozin Horizon (the lower Kokala Formation) of Mangyshlak almost lack *Coniopteris* leaf remains, which, when occurring, are generally undefinable at the species level. However, taphofloras from the top layers of the Kokala and Tonasha formations of Mangyshlak show the presence of several *Coniopteris* species (*C. nerifolia* Genk., *C. margaretae* Harris, and *C. furssenkoi* Pryn.) typical of the Middle Jurassic (Vakhrameev, 1970). The *Nillsonia* genus also becomes more diverse in the Early–Middle Jurassic taphofloras of this region. Similar changes in composition of *Coniopteris* and *Nilssonia* genera were also observed in the Early–Middle Jurassic taphofloras of the Kuznetsk coal basin (Kirichkova *et al.*, 1992). Therefore, the Kurkureu–Boroldai plant assemblage of southern Kazakhstan and its analogues can be correlated, based on their evolutionary level, with the Kokala, Chirchil', and, probably, Kelendin taphofloras of Mangyshlak, whose age was adopted at the Kazakhstan stratigraphic meeting (1986) as the Toarcian–Aalenian.

The Kashkarata Formation overlying the Boroldai Formation in the reference section of the Karatau Range is almost barren of plant remains (Sevryugin *et al.*, 1989, 1990). According to Orlovskaya (Doludenko and

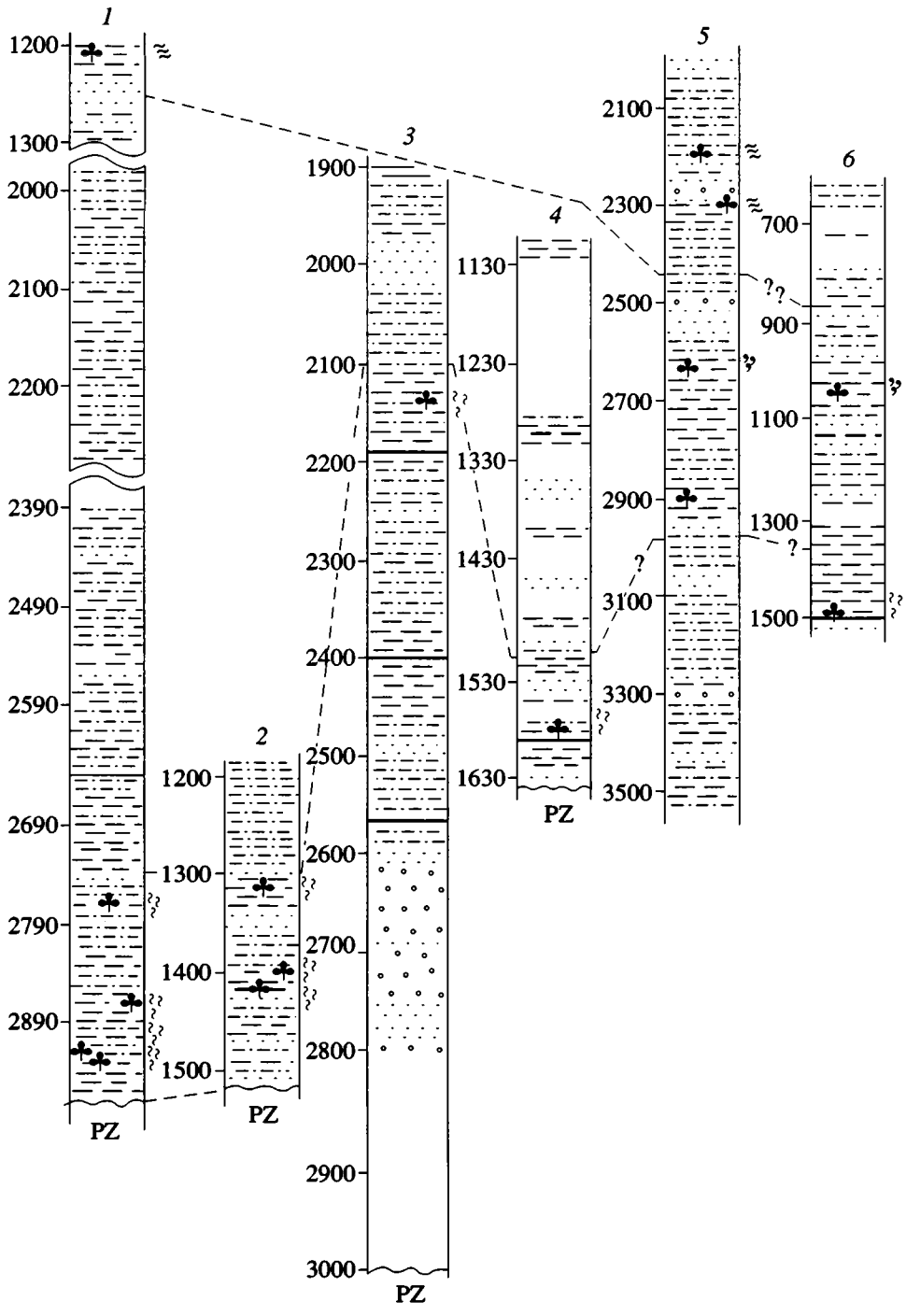


Fig. 4. Distribution of the Boroldai floral subassemblage (a), and Borolsai (c), and Karabastau (d) correlative plant assemblages in wells drilled in the southern Turgai depression (according to geologists from Yuzhkazgeologiya) (*1*) Sazymbai area, Well 2-P; (*2*) Aryskum area, Well 15-S; (*3*) Akshabulak area, Well 1-P; (*4*) Kumkol' area, Well 5-G; (*5*) Bozingen area, Well 1-P; (*6*) Bazingen area, Well 13-S. For the legend see Figs. 2 and 3.

Orlovskaya, 1976), the impoverished plant assemblage from the Kashkarata Formation is still similar to that from the Boroldai Formation, and bears all features of the Siberian paleofloral province. In its stratigraphic position, the Kashkarata Formation corresponds to the Karagan and Duzbai formations of the northern Turgai depression, whose plant assemblages show a distinct similarity with those from the Karadiirmen' Formation of Mangyshlak and western Kazakhstan (Vakhrameev, 1964; Kirichkova *et al.*, 1989). In the southern Turgai depression, the 400-m-thick sequence of siltstones, sandstones, dark-gray to black claystones, and basal

Table 4. Distribution of the Boroldai plant assemblage in well sections of the southern Turgai depression

Species	Akshabulak, 1-P, depth 2090–2092 m	Sazymbai, 2-P, depth 2781–2930 m	Aryskum, 15-S, depth 1344–1470 m	Kumkol', 5-G, depth 1544–1552 m
Neocalamites sp.			+	
Equisetites turgaicus (Vlad.) Kiritch.		+		
Coniopteris spetabilis Brick		cf.	sp.	+
C. murrajana (Brongn.) Brongn.	+			
Cladophlebis cf. *nebbensis* (Brongn.) Nath.				+
C. whitbiensis (Brongn.) Brongn.			+	
C. czokpakensis Orlovs.				+
C. cf. *sewardii* Johans.				+
Lobifolia (Eboracia?) sp.		+		
Anomozamites cf. *kornilovae* Orlovs.				+
Sphenobaiera sp.			+	
Czekanowskia ex gr. *rigida* Heer		+		
Cz. ex gr. *latifolia* Tur.-Ket.				+
Ferganiella lanceolata Brick			+	
Pagiophyllum setosum (Phill.) Sew.				+
Pityophyllum sp.			+	

conglomerates united into the Doshchan Formation (Buvalkin and Soldatova, 1988) can probably be correlated with the Kashkarata Formation. The Doshchan Formation is drilled by Well 2-P (depth interval 2100–2600 m) in the Sazymbai area, by Well 1-P (depth interval 1900–2100 m) in the Akshabulak area, and by Well 1-P (depth interval 3000–3500 m) in the Bazingen area. Because of a poor recovery (lithological columns in Fig. 4 were compiled by geologists from the Yuzhkazgeologiya based on geophysical data), no plant remains are known from this stratigraphic interval.

Taphofloras from the upper portion of the Jurassic section in the Karatau Range, namely from the Borolsai and Karabastau formations, represent typical paleofloras of the Euro-Sinian paleofloral province. Owing to recent investigations (Sevryugin *et al.*, 1989, 1990; Doludenko, 1984; Doludenko *et al.*, 1989, 1990), the stratigraphy of these deposits was considerably refined and substantiated by paleofloral data. The revised stratigraphic scheme of these deposits was included into the Jurassic stratigraphic scheme of Kazakhstan adopted at the 1986 meeting. The Borolsai correlative plant assemblage from the Borolsai Formation of the Karatau Range significantly differs from that of the Boroldai Formation in the ratio of characteristic plant groups. The leading role in the former belongs to conifers of *Elatocladus, Pagiophyllum*, and *Brachyphyllum* genera, bennettites of *Pterophyllum, Williamsoniella*, and *Anomozamites* genera, and *Sagenopteris* species. Ferns are represented by small-leaved *Coniopteris simplex* (L. et H.) Harris. The Bathonian age of the Borolsai plant assemblage is determined based on its similarity to the Sarydiirmen' taphofloras of Mangyshlak whose age, in turn, was confirmed by the Bathonian ammonite fauna (Beznosov, 1972; Savel'ev *et al.*, 1973; Kirichkova *et al.*, 1989; Doludenko *et al.*, 1989).

Recently, we found analogues of the Borolsai plant assemblage in the lower Toguz Formation of the Lenger coal basin (Doludenko *et al.*, 1995), and in wells drilled in the southern Turgai depression.

In the Lenger depression, the plant assemblage of the Borolsai type (Plate II, *6–8*; Plate III, *1–13*) was collected from the lower and middle Toguz Formation in outcrops of the Ashchi River (Fig. 5). It consists of horsetails *Equisetites beani* (Bunb.) Sew. and *E.* cf. *acmophyllus* Kiritch., abundant small-leaved ferns *Coniopteris vialovae* Tur.-Ket., *C.* cf. *simplex* (L. et H.) Harris, and *C.* cf. *furssenkoi* Pryn. associated with cycadophytes *Nilssonia* cf. *baranovae* Burak. (leaf fragment). Upsection, the small shoot of conifers *Elatocladus* cf. *minuta* Dolud. was found. The composition of this complex is identical with that from the Borolsai Formation of the Karatau Range and Sarydiirmen' Formation of Mangyshlak (Kirichkova *et al.*, 1989; Doludenko *et al.*, 1989). A similar complex with small-pinnuled *Coniopteris* forms and conifers of *Pagiophyllum* and *Elatocladus* genera occurs in wells and outcrops of the Bozingen area (the Bozingen ravine) of the southern Turgai depression. Analogues of the Borolsai

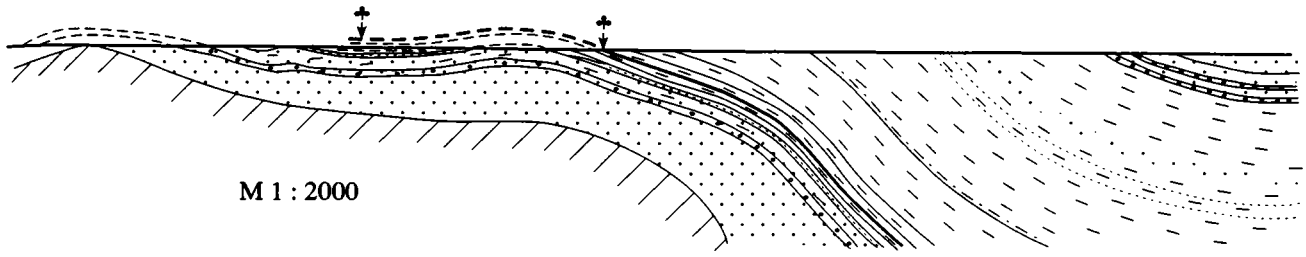


Fig. 5. The section of the lower portion of the Toguz Formation in the Ashchi River outcrop, the Lenger depression. For the legend see Fig. 2.

Formation (Fig. 4) were penetrated there by Well 1-P in a depth interval of 2600–3000 m, and by Well 13-S in a depth interval of 850–1200 m. They are represented by black bituminous shales with gray siltstone and sandstone interbeds (the Karagansai Formation?). Siltstone intercalations in the Bozingen ravine outcrop yielded *Coniopteris furssenkoi* Pryn., *C.* cf. *porcina* Pryn., and conifers with scaly leaves (Table 5).

The remarkably stable composition of taphofloras of the Borolsai–Sarydiirmen' type shows for the first time that the Bathonian age can be more confidently ascribed not only to the Borolsai Formation of the Karatau Range, but also to the lower Toguz Formation of the Lenger depression and their analogues penetrated by wells in the southern Turgai depression.

The plant assemblage from the upper Toguz Formation of the Lenger depression was sampled in the open pit near the ceramic plant. Here, the member of variegated clays with sandstone and siltstone interbeds is exposed. Light-gray clays yielded *Equisetites* sp., *Gleichenoides kazachstanica* Kiritch., *Coniopteris* cf. *furssenkoi* Pryn., *Pterophyllum* sp., *Ixostrobus heeri* Pryn., *Schizolepis lengerensis* Dolud. et Kostina, *Pityospermum lengerensis* Dolud. et Kostina, *Pityocladus kobukensis* Sew., *Pityophyllum angustifolium* (Nath.) Moeller, *Pityanthus* sp., *Swedenborgia* cf. *longiloba* Stanisl., *Podozamites* sp., *Araucarites* sp., and *Sama-*

Table 5. Distribution of the Borolsai plant assemblage in well sections and outcrops of the southern Turgai depression

Species	Bozingen area		Bozingen Ravine
	1-P, 2658–2925 m	13-S, 1000–1010 m	
Equisetites beanii (Bunb.) Sew.			+
E. lateralis (Phill.) Harris		+	
Hausmannia sp.			+
Phlebopteris polypodioides (Brongn.) Brongn.			
Coniopteris hymenophylloides (Brongn.) Sew.	cf.	+	
C. furssenkoi Pryn.	+		
C. cf. *nerifolia* Genk.	+		
C. cf. *porcina* Pryn.			+
Eboracia lobifolia (Phill.) Thomas	+		+
Cladophlebis sp.			+
Czekanowskia ex gr. *latifolia* Tur.-Ket.	+		
Erethmophyllum sp.			+
Nilssonia sp.		+	+
Nilssoniopteris sp.			+
Pagiophyllum setosum (Brongn.) Sew.			+
Elatocladus subzamioides Dolud.			+
Pityophyllum sp.	+	+	+
Schizolepis sp.			+
Pityospermum sp.			+

ropsis sp. (Plate III, figs. *14–26*) (Doludenko *et al.*, 1995). The taxa ratio in this assemblage is identical with that in the Borolsai Formation. However, the presence of ferns of the *Gleichenoides* genus and conifers of the *Araucarites* genus in the upper Toguz plant assemblage suggests its younger age as compared to the Borolsai and Sarydiirmen' taphofloras. Moreover, the plant assemblages similar to those from ceramic clays of the Lenger depression are unknown in the most complete sections of the Karatau Range and western Kazakhstan (Mangyshlak and the northern Caspian depression). In the Leont'ev depression (the Karatau Range), the Borolsai Formation is overlain conformably by the Karabastau Formation. Well-studied Karabastau taphofloras significantly differ in characteristic species composition from both the Borolsai and Ceramic Clay plant assemblages, and reflect the later evolutionary stage of floras in the Euro-Sinian paleofloral province (Doludenko and Orlovskaya, 1976; Doludenko, 1984).

In the Jurassic sections of western Kazakhstan and reference sections of Mangyshlak, the coastal-marine Sarydiirmen' Formation of the Lower-Middle Jurassic is overlain with significant stratigraphic unconformity by the marine Chagabulak Formation, whose Callovian–Oxfordian–early Kimmeridgian age is substantiated by the ammonite and foraminifer faunas and palynological data (Beznosov, 1972; Savel'ev *et al.*, 1973; Kirichkova *et al.*, 1989). The palynologic characteristics of the Chagabulak Formation of Mangyshlak are very similar to those of the Karabastau Formation of the Karatau Range. All this allows us to suggest a hiatus between these two formations included in the single Jurassic continental section of the Karatau Range, which encompasses, by analogy with sections in Mangyshlak, the late Bathonian–earliest Callovian. In the Lenger depression, this interval was a time of accumulation of the upper Toguz Formation with the plant assemblage consisting of the *Gleichenoides* fern species and various conifers, mainly ancient Pinaceae of *Schizolepis, Pityospermum, Pityocladus*, *Samaropsis*, and *Araucarites* genera. Most likely, the plant assemblage from the Ceramic Clay member in the Lenger depression (the upper Toguz plant assemblage) represents another, previously unknown, link in the Jurassic floral succession of Kazakhstan, transitional between the Borolsai and Karabastau paleofloras. No analogues of this plant assemblage have been recorded thus far elsewhere in Kazakhstan. Yet, it is not inconceivable that the Kumkol' Formation of the southern Turgai depression, composed of gray sandstones with siltstone and claystone interbeds (Buvalkin *et al.*, 1989; Buvalkin and Soldatova, 1988), might be correlated in the future with the upper Toguz Formation of the Lenger depression.

The Karabastau correlative plant assemblage of the Jurassic section in southern Kazakhstan is distinguished in the Karabastau Formation of the Karatau Range. The lithology, stratigraphic position, and paleofloral remains of this formation are well studied (Sevryugin *et al.*, 1989; 1990; Doludenko and Orlovskaya 1976; Doludenko *et al.*, 1990). The Karabastau plant assemblage is dominated by conifers of the Cheirolepidiaceae family (*Pagiophyllum* and *Brachyphillum* genera), bennettites (*Ptilophyllum* and *Otozamites* genera), cycads (*Paracycas* and *Cycadites* genera), and ferns of the *Stachypteris* genus. This is the typical Jurassic flora of the Euro-Sinian paleofloral province (Doludenko, 1984), whose late Callovian–Kimmeridgian age was determined by analogy with Late Jurassic floras of Georgia and Europe and supported by palynological data (Sevryugin *et al.*, 1989; Sakulina, 1968, 1976). Based on the stratigraphic position and similarity of palynological characteristics, the Karabastau Formation is correlated with the Chagabulak Formation of western Kazakhstan (Table 6). Analogues of the Karabastau plant assemblage with conifers were found in three wells in the southern Turgai depression (Fig. 4): Well 1-P in the Bozingen area, where *Elatocladus minutus* Dolud., *Elatocladus* sp., and *Pityospermum* sp. occur (depth interval of 2187–2224 m); Well 19-S in the Kumkol' area (*Coniopteris* sp., *Ptilophyllum* sp., and *Araucarites vassilevskiana* Tur.-Ket.; depth interval of 884–885 m); and Well 2-P in the Sazymbai area (*Gleichenia* sp. and *Pagiophyllum* sp.; depth 1208 m). These wells probably penetrated the Akshabulak Formation (Buvalkin *et al.*, 1988, 1989), which might be

Plate III. (*1–13*) The plant assemblage from the lower Toguz Formation [all specimens were sampled in the lower Toguz Formation of the Lenger depression, the Ashchi River locality, the Middle Jurassic (Bathonian)]. (*1a, 1b*) *Coniopteris* cf. *furssenkoi* Pryn., fragments of sterile feathers, specimen 853/35, *1a*, ×2, (*2–8*) *Coniopteris vialovae* Tur.-Ket., inprints of sterile and fertile (*8*) feathers, specimens 853/38, 853/37, 853/36, 853/39, 853/40, 853/41, and 853/42, respectively; *4a, 5b, 6b, 7b*, and *8b*, ×2. (*9–11*) *Coniopteris* cf. *simplex* (L. et H.) Harris, imprints of sterile leaves, specimens 853/43, 853/44, and 853/45, respectively, *10b*, ×2. (*12a, 12b*) *Elatocladus minutus* Dolud., shoot fragment with leaves, specimen 852/85, *12b*, ×2, (*13*) *Nilssonia* cf. *baranovae* Burak., fragment of the segmented leaf, specimen 853/86. (*14–26*) the Ceramic Clay plant assemblage (all specimens were sampled in the upper Toguz Formation, the Lenger depression, the quarry near the ceramic plant, the Uppermost Jurassic):

(*14–16*) *Gleichenoides kazachstanica* Kiritch., imprints of pinnate leaves, specimens 853/46, 853/47, and 853/51, respectively. (*17–19*) *Schizolepis lengerensis* Dolud. et Kostina, female cones, specimens 853/7, 853/6, and 853/24, respectively. (*20a, 20b*) *Pityospermum lengerensis* Dolud. et Kostina, thistledown imprint, specimen 853/12, *20b*, ×2, (*21a, 21b*) *Cycadocarpidium* sp., megasporophyllum, specimen 853/19, *21b*, ×2, (*22*) *Ixostrobus* sp., microstrobilus, specimen 853/20. (*23*) *Swedenborgia longiloba* Stanisl., specimen 853/16. (*24*) *Pityocladus kobukensis* Sew., shoot fragment, specimen 853/15. (*25a, 25b*) *Gnetales*(?) sp., scale, specimen 853/18, *25b*, ×2. (*26a, 26b*) *Pithyantus* sp., scattered microstrobilae, specimen 853/95, *26b*, ×2.

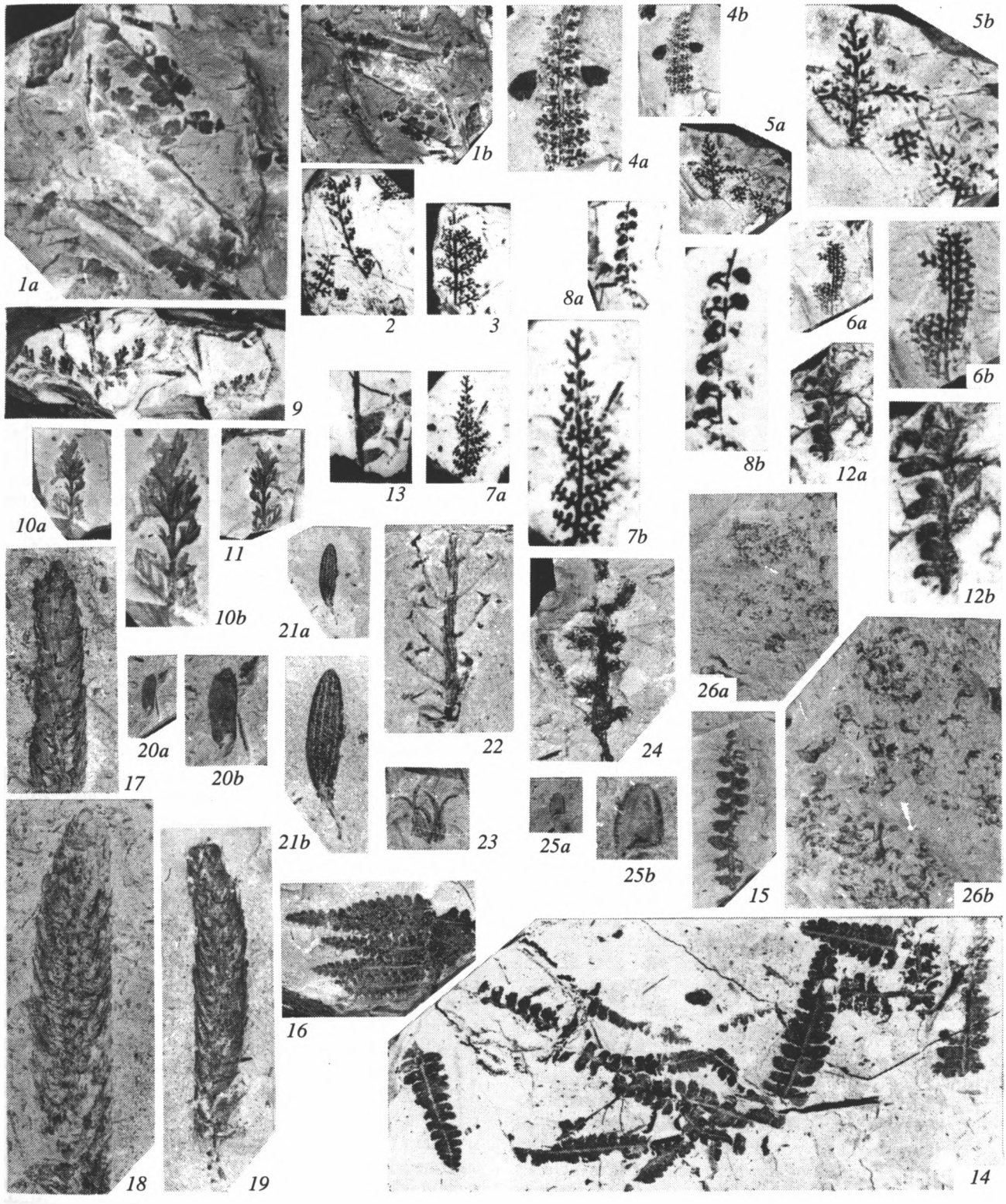

1a
1b
2
3
4a
4b
5a
5b
6a
6b
7a
7b
8a
8b
9
10a
10b
11
12a
12b
13
14
15
16
17
18
19
20a
20b
21a
21b
22
23
24
25a
25b
26a
26b

Table 6. Correlation of Jurassic reference sections in western and southern Kazakhstan based on fossil plant remains

Series	Stage	Southern Kazakhstan: assemblages: plant remains	Southern Kazakhstan: Karatau Range	Western Kazakhstan: Mangyshlak	Western Kazakhstan: assemblages: plant remains	Western Kazakhstan: assemblages: spores and pollen	Horizon	Stage	Series
J_3			Balabugun' Fm.						J_3
		Karabastau	Karabastau Fm.	Chagabulak Fm.		Karamai	Sarydiirmen'–Karamai		
J_2	Clv	Ceramic Clay plant assemblage						Clv	J_2
	Bth	Borolsai	Borolsai Fm.	Sarydiirmen' Fm.	Sarydiirmen'			Bth	
	Baj		Kashkarata Fm.	Bazarli Fm.					
				Karadiirmen' Fm.	Karadiirmen'	Tushchebek	Mangyshlak	Baj	
						Karashimrau			
	Aal	Kurkureu–Boroldai / Boroldai	Boroldai Fm.	Tonasha Fm.	Kalenda	Tonasha		Aal	
				Kokala Fm. upper member	Chirchil'				
	Toa	Kurkureu	Kurkureu Fm.	Kokala Fm. lower member	Kokala		Ergozi	Toa	
J_1	Plb	Chokpak–Kel'te-mashat	Coal-bearing unit	Ergozi Fm.		Zhagi		Plb	J_1
	Het Sin	?—						Het Sin	

correlated in the future with the Karabastau Formation of the Karatau Range.

The Jurassic section in the Leont'ev depression (the Karatau Range) terminates with the Balabugun' Formation barren of plant remains. Based on palynological evidence, it is conditionally dated as the Late Jurassic (Sevryugin *et al.*, 1989).

Thus, the revision of the taxonomic composition and stratigraphic position of Jurassic taphofloras in the reference sections of southern and western Kazakhstan for the first time made it possible to obtain paleofloral substantiation of the correlation of coal-bearing sequences both within individual and different basins. Important data were also obtained on the refinement of the paleophytogeographic situation. It is well known that during the Jurassic, the Kazakhstani territory was occupied by floras of two paleofloral provinces (Vakhrameev, 1964, 1970, 1988): the flora of the Euro-Sinian type was spread over western Kazakhstan, while that of the Siberian type was characteristic of eastern Kazakhstan. The boundary between the Euro-Sinian and Siberian paleofloral provinces was located almost in the middle of the Kazakhstani territory, somewhat southward of 45°N being oriented from the northwest to southeast and further to the south. The analysis of Early and Middle Jurassic floras of Kazakhstan showed that it was unstable during that time interval. In the Early–earliest Middle Jurassic, the flora of the Siberian type with diverse *Cladophlebis* species, associated with horsetails of *Neocalamites* and *Eqisetites* genera, and conifers of *Podozamites* and *Pityophyllum* genera, was spread over the greater Kazakhstani territory up to its southernmost areas (the Lenger, Kel'temashat, and Leont'ev depressions). Therefore, the Early–Middle Jurassic taphofloras of these regions are taxonomically similar to those of the Siberian plaeofloral province, which were recorded in eastern Kazakhstan (Maikyuben' and Alakol' areas) and southwestern Siberia (Kirichkova *et al.*, 1972). Coeval taphofloras of western Kazakhstan (Mangyshlak and Tuarkyr areas) readily correlate with floras of the Caucasus, Iran, and England, i.e., with floras of the Euro-Sinian paleofloral province (Kirichkova *et al.*, 1989). At that time, the boundary between these paleofloral provinces was most likely located in significantly more southern areas than was previously thought, it was striking south of 40°N from the southern Urals (east of the Orsk coal basin) to the south, and then to the southeast up to northern China (Fig. 1). The paleogeographic reorganizations and transgression of the Tethys from the southeast during the second half of the Jurassic (*Paleogeografiya* ..., 1975) significantly affected the climatic environments, which resulted in the retreat of Siberian floras far to the north and east. In the territory of southern and, probably, eastern Kazakhstan, floras of the Euro-Sinian type became widespread. They were represented by Borolsai, Toguz, and Karabastau taphoflo-

ras of Kazakhstan, and by floras of the Ilek Formation occurring in the Ilek River basin of the northeastern Caspian depression (Orlovskaya, 1977). In the late Middle–Late Jurassic, the boundary between paleofloral provinces occupied the latitudinal position most likely close to 50°N (Fig. 1).

CONCLUSION

Thus, the studied taxonomic composition and stratigraphic distribution of taphofloras and thorough analysis of original and published paleobotanical and geological data shed new light on the history of Jurassic continental deposits in Kazakhstan.

(1) Five phytostratigraphic (correlative) assemblages were defined in reference sections of Jurassic terrestrial deposits in southern Kazakhstan (the Leont'ev depression in Karatau, and Lenger, and Keltemashat basins). These are the Chokpak–Kel'temashat (Early Jurassic), Kurkureu–Boroldai (terminal Early–earliest Middle Jurassic), Borolsai (Middle Jurassic, Bathonian), Ceramic Clay (Middle Jurassic, late Bathonian–early Callovian), and Karabastau (terminal Middle Jurassic, late Callovian–Late Jurassic, Oxfordian–Kimmeridgian) plant assemblages. The age of the assemblages was determined by comparison with dated floras from the reference sections of West Siberia and western Kazakhstan; in the latter region, the age of corresponding plant assemblages is controlled by marine faunas.

(2) Stratigraphy and correlation of sections comprising the lower part of the Jurassic sequence in southern Kazakhstan have been refined, and distant correlations of Lower Jurassic deposits between coal-bearing basins throughout Kazakhstan have been substantiated by paleofloral data. Defined correlative plant assemblages were traced in the recently discovered oil-and-gas field in the southern Turgai depression, where they were used to outline the stratigraphy of the thick Jurassic sequence penetrated by wells.

(3) The established and dated plant assemblage from the Ceramic Clay Member represents a new link in the Jurassic floral succession in Kazakhstan.

(4) It was established that the composition of the Chokpak–Kel'temashat and Borolsai phytostratigraphic assemblages remained stable over the great territory, and units with these assemblages can be treated as the marker levels. These levels provide the basis to correlate the reference sections of Jurassic terrestrial and coastal-marine deposits in southern and western Kazakhstan.

(5) A new version of the unified stratigraphic scheme of Jurassic deposits of Kazakhstan was elaborated.

(6) The refined phytochoria boundaries show that during the Early Jurassic and first half of the Middle Jurassic, floras of the Siberian paleofloral province were widespread throughout the Kazakhstani territory except in its western areas. The boundary of this province was located in significantly more southern areas than was thought previously, namely south of 40°N but not 45°N. Paleogeographic reorganizations, particularly the transgression of the Tethys, and formation of the arid belt (Vakhrameev *et al.*, 1970) in the mid-Middle Jurassic resulted in the expansion of the Euro-Sinian paleoflora in the Kazakhstani territory. The boundary between these two provinces migrated far northeastward, and occupied an almost latitudinal position close to 50°N.

ACKNOWLEDGMENTS

The collection of fossil plants from Jurassic deposits of southern Kazakhstan was sampled together with N.N. Sevryugin and O.A. Fedorenko, geologists from the Yuzhkazgeologiya Scientific-Industrial Organization, in 1985–1990. Geological data were submitted by N.N. Sevryugin and G.V. Sakulina, to whom we express our sincere gratitude. The work was financially supported by the International Science Foundation and the Academy of Natural Sciences.

Reviewer M.A. Akhmet'ev

REFERENCES

Beznosov, N.V., Age and Nomenclature of Jurassic Formations of the Eastern Ciscaucasia and Their Correlation with Coeval Formations of Mangyshlak and Tuarkyr, in *Novye dannye po stratigrafii mezokainozoya Srednei Azii* (New Data on the Mesozoic–Cenozoic Stratigraphy of Middle Asia), Moscow: Vsesoyuzn. Nauchn.-Issled. Geol. Neft. Inst., 1972, vol. 114, pp. 3–17.

Buvalkin, A.K., Stratigraphy of Jurassic Deposits of the Taskomyrsai Coal Field, *Uch. Zap. Kaz. Univ.*, 1958, vol. 37, no. 4, pp. 46–60.

Buvalkin, A.K., The Ili Coal Basin, *Vestn. Akad. Nauk KazSSR*, 1964, no. 1, pp. 47–58.

Buvalkin, A.K., *Yurskie otlozheniya Vostochnogo Kazakhstana* (Jurassic Deposits of Eastern Kazakhstan), Alma Ata: Nauka, 1978.

Buvalkin, A.K. and Soldatova, N.S., Geochemistry of Jurassic Oil-Bearing Deposits of the Aryskum Basin (Southern Turgai Depression), *Izv. Akad. Nauk KazSSR, Ser. Geol.*, 1988, no. 1, pp. 59–67.

Buvalkin, A.K., Soldatova, N.S., and Mursalimov, S.M., Geochemistry of Jurassic and Oil-Bearing Deposits of the Aryksum and Dzhilanchik Basins (Southern Turgai Depression), *Izv. Akad. Nauk KazSSR, Ser. Geol.*, 1989, no. 6, pp. 54–60.

Buvalkin, A.K., Zhaimin, M.I., and Kotova, L.I., Presence of Hettangian-Sinemurian Marine Deposits in the Coal-Bearing Belt of the Karatau Range, *Izv. Akad. Nauk KazSSR, Ser. Geol.*, 1983, no. 3, pp. 21–30.

Doludenko, M.P., *Pozdneyurskie flory yugo-zapadnoi Evrazii* (Late Jurassic Floras of Southwestern Eurasia), Moscow: Nauka, 1984.

Doludenko, M.P., Kirichkova, A.I., and Kostina, E.I., Jurassic Flora of the Lenger Coal Deposit (Southern Kazakhstan), *Paleontol. Zh.*, 1995, no. 1, pp. 98–109.

Doludenko, M.P., Kirichkova, A.I., Sakulina, G.V., *et al.*, Flora from the Borolsai Formation of the Karatau Range (Southern Kazakhstan), *Paleontol. Zh.*, 1989, no. 4, pp. 88–100.

Doludenko, M.P. and Orlovskaya, E.R., *Yurskaya flora Karatau* (The Jurassic Flora of Karatau), Moscow: Nauka, 1976.

Doludenko, M.P., Sakulina, G.V., and Ponomarenko, A.G., Geological Structure of the Unique Aulie Locality of the Late Jurassic Fauna and Flora (Karatau, Southern Kazakhstan), *Prepint Geol. Inst., Russ. Acad. Sci.*, Moscow, 1990.

Kirichkova, A.I., Jurassic and Early Cretaceous Paleofloras of the Siberian Paleofloral Province and Detailed Phytostratigraphy, in *Yarusnye i zonal'nye shkaly Boreal'nogo mezozoya SSSR* (Stage and Zonal Schemes of the Boreal Mesozoic of the USSR), Moscow: Nauka, 1989, pp. 145–158.

Kirichkova, A.I., Modern Taxonomy of Fossil Plants and Paleofloral Successions as the Basis for Detailed Phytostratigraphic Studies, in *Stratigrafiya triasovykh i yurskikh otlozhenii neftegazonosnykh basseinov SSSR* (Triassic and Jurassic Stratigraphy of Oil-and-Gas Bearing Basins of the USSR), Leningrad: Vsesoyuzn. Nauchn.-Issled. Geol.-Razved. Inst., 1982, pp. 95–114.

Kirichkova, A.I., Jurassic and Early Cretaceous Paleofloras of the Siberian Paleofloral Province and Detailed Phytostratigraphy, in *Yarusnye i zonal'nye shkaly Boreal'nogo mezozoya SSSR* (Stage and Zonal Schemes of the Boreal Mesozoic of the USSR), Moscow: Nauka, 1989, pp. 145–158.

Kirichkova, A.I., Batyaeva, S.K., and Bystritskaya, L.I., *Fitostratigrafiya yurskikh otlozhenii yuga Zapadnoi Sibiri* (Jurassic Phytostratigraphy of Southern West Siberia), Moscow: Nedra, 1992.

Kirichkova, A.I., Timoshina, N.A., and Men'shikova, N.Ya., Jurassic Phytostratigraphy of Mangyshlak, *Sov. Geol.*, 1989, no. 11, pp. 73–82.

Meyen, S.V., *Teoreticheskie problemy paleobotaniki* (Theoretical Problems of Paleobotany), Moscow: Nauka, 1990.

Orlovskaya, E.R., Early Mesozoic Flora from the Ilek River Basin, in *Materialy po istorii fauny i flory Kazakhstana* (Materials on the History of Fauna and Flora in Kazakhstan), Alma Ata: Nauka, 1977, pp. 106–125.

Orlovskaya, E.R., Lower Mesozoic Flora of Eastern Kazakhstan, in *Nizhnemezozoiskie uglenosnye otlozheniya Kazakhstana* (Lower Mesozoic Coal-Bearing Deposits of Kazakhstan), Alma Ata: Nauka, 1968, pp. 63–81.

Orlovskaya, E.R., Jurassic Flora from the Ili Coal-Bearing Basin, in *Materialy po istorii fauny i flory Kazakhstana* (Materials on the History of Fauna and Flora in Kazakhstan), Alma Ata: Nauka, 1974, pp. 93–107.

Paleogeografiya SSSR. Ob"yasnitel'naya zapiska k atlasu paleogeograficheskikh kart SSSR (Paleogeography of the USSR: Explanatory Notes to the Atlas of Paleogeographic Maps of the USSSR), Moscow: Nedra, 1975, vol. 3.

Sakulina, G.V., Upper Jurassic Spores and Pollen Assemblages of Kazakhstan, in *Nizhnemezozoiskie uglenosnye otlozheniya Kazakhstana* (Lower Mesozoic Coal-Bearing Deposits of Kazakhstan), Alma Ata: Nauka, 1968, pp. 119–124.

Sakulina, G.V., Triassic–Jurassic Palynology and Stratigraphy of Southern Kazakhstan, in *Palinologiya Kazakhstana* (Palynology of Kazakhstan), Alma Ata: Kazakh. Inst. Mineral. Syr'ya, 1976, issue 2, pp. 36–45.

Savel'ev, A.A., Kalugin, A.K., Azbel', A.Ya., *et al.*, New Data on the Jurassic Stratigraphy of Mangyshlak, in *Novye dannye po geologii i neftegazonosnosti Mangyshlaka* (New Data on Geology and Oil–Gas Potential in Mangyshlak), Leningrad: Vsesoyuzn. Nauchn.-Issled. Geol.-Razved. Inst., 1973, pp. 19–34.

Sevryugin, N.N., Doludenko, M.P., Kirichkova, A.I., *et al.*, *Stratigrafiya i flora yurskikh otlozhenii khrebta Karatau (Yuzhnyi Kazakhstan)* (Jurassic Stratigraphy and Flora of the Karatau Range, Southern Kazakhstan), Moscow: Geol. Inst. Akad. Nauk SSSR, 1989.

Sevryugin, N.N, Fedorenko, O.A., Doludenko, M.P., *et al.*, Jurassic Deposits of the Karatau Range (Southern Kazakhstan), *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1990, no. 7, pp. 63–77.

Vakhrameev, V.A., *Yurskie i rannemelovye flory Evrazii i paleofloristicheskie provintsii etogo vremeni* (Jurassic and Early Cretaceous Floras of Eurasia and Paleofloral Provinces of That Time), Moscow: Nauka, 1964.

Vakhrameev, V.A., Stage Subdivision of the Middle Jurassic of the Southern USSR Based on Paleobotanical Data, *Sov. Geol.*, 1969, no. 6, pp. 8–18.

Vakhrameev, V.A., Stratigraphy and Correlation of Continental Deposits Based on Paleobotanical Data, *Sov. Geol.*, 1982, no. 1, pp. 58–67.

Vakhrameev, V.A., *Yurskie i melovye flory i klimaty Zemli* (Jurassic and Cretaceous Floras of the Earth), Moscow: Nauka, 1988.

Vakhrameev, V.A., Dobruskina, I.A., Zaklinskaya, E.D., *et al.*, *Paleozoiskie i mezozoiskie flory Evrazii i fitogeografiya etogo vremeni* (Paleozoic and Mesozoic Floras of Eurasia and Phytogeography of That Time), Moscow: Nauka, 1970.

Stratigraphy and Geological Correlation, Vol. 4, No. 5, 1996, pp. 467–479. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 5, 1996, pp. 53–66.
Original Russian Text Copyright © 1996 by Repin, Rashwan.
English Translation Copyright © 1996 by МАИК Наука/Interperiodica Publishing (Russia).

Chronology and Biochores of Callovian Ammonites from Mangyshlak

Yu. S. Repin and N. Rashwan

All-Russian Research Institute of Oil Geological Exploration, Liteinyi pr. 39, St. Petersburg, 191104 Russia

Received December 16, 1994

Abstract—A comprehensive revision of ammonites, which were collected by the scientific group of M.S. Mesezhnikov in 1985, shows the high taxonomic diversity of these fossils, and affords an opportunity to refine zonal and intrazonal Callovian stratigraphy of Mangyshlak. Most of the species and all distinguished genera from this region display a wide geographic distribution, and are of the subboreal type. The ammonite assemblages of Western Europe and Mangyshlak include many common taxa, which enable a direct correlation with the standard zonation of the Callovian that is useful for the detailed biozonation of local sequences. All standard zones, with the exception of the lowermost one, and some subzones were distinguished in the Callovian deposits of Mangyshlak. All of these units, except for the *Macrocephalites herveyi* Zone, are marked by index species and other characteristic forms of respective assemblages. Studied features of the very representative ammonite assemblage from the Callovian deposits of Mangyshlak afford an opportunity to better understand its structure and chorology. The comparative analysis of this and other ammonite assemblages from nearby areas reveals the character of chorologic changes and their evolution with time along the profile from the Pechora River basin in the north to the Kugitang Range in the south. The obtained data suggest a new position for the boundary between the Boreal and Tethyan biogeographic provinces.

Key words: *ammonite assemblages, Callovian, substage, zone, dominants, index species, paleozoochore, Mangyshlak.*

This paper presents data obtained in the course of the comprehensive revision of ammonite assemblages, which have been collected by scientists of the All-Russian Research Institute of Oil Geological Exploration under the guidance of M.S. Mesezhnikov during field work in 1985 in the Mangyshlak. In addition, we used paleontological samples from the Callovian deposits kindly submitted by A.A. Savel'ev, who studied this region for a long period.

The following description of geological sections is based on unpublished materials of M.S. Mesezhnikov and A.A. Kalugin, and on the data of Savel'ev and his colleagues (Savel'ev, 1963; Savel'ev *et al.*, 1973). The description is supplemented with our paleontological determinations.

Doshchan Section

The section is located on the northern slope of the East Karatau Range, 3 km eastward of the Mt. Sary-Diirmen', and includes the following units (Fig. 1):

(1) Clay, light gray (1.4 m);

(2) Clay, greenish-gray, silty, enclosing sand interlayers in the upper part (1.6 m);

(3) Clay, greenish-gray, with marl concretions (1.1 m);

(4) Sand, gray, fine-grained (1.75 m);

(5) Sandstone, gray, fine-grained (0.45 m);

(6) Sand, gray, fine-grained (1.0 m);

(7) Silty clay, greenish-gray, with 10- to 20-cm-thick intercalations of gray fine-grained sand (1.65 m);

(8) Bed of marl concretions bearing *Proplanulites excentricus tenuis* Repin, *Kepplerites (Gowericeras) gowerianus* (Sow.), and *K. (Toricellites)* sp. indet. (0.5 m);

(9) Clay, dark gray, silty at the base and sandy above, bearing *Proplanulites excentricus tenuis* Repin (2.0 m);

(10) Marl, gray, grumous, with fossiliferous concretions, which yielded *Kepplerites (Gowericeras) gowerianus* (Sow.), *Macrocephalites (Pleurocephalites)* cf. *pila* (Nik.), *M. (Kamptokephalites)* sp., *Proplanulites excentricus tenuis* Repin, *P. arciruga inflatus* Repin, *Chamoussetia* ex gr. *chamousseti* (Orbigny), and *Hecticoceras* sp. indet. (0.4 m);

(11) Sand, yellowish-gray, fine-grained, with clay laminae (1.0 m);

(12) Sandstone, greenish-gray, bearing *Kepplerites (Gowericeras) gowerianus* (Sow.), *K. (Toricellites) hexagonus* (Loewe), *Proplanulites* cf. *koenigi* (Sow.), *P. teisseyrei* Tornquist, *P. excentricus tenuis* Repin, and *P. arciruga inflatus* Repin (0.1 m);

(13) Sand, greenish-gray, fine-grained (2.2 m);

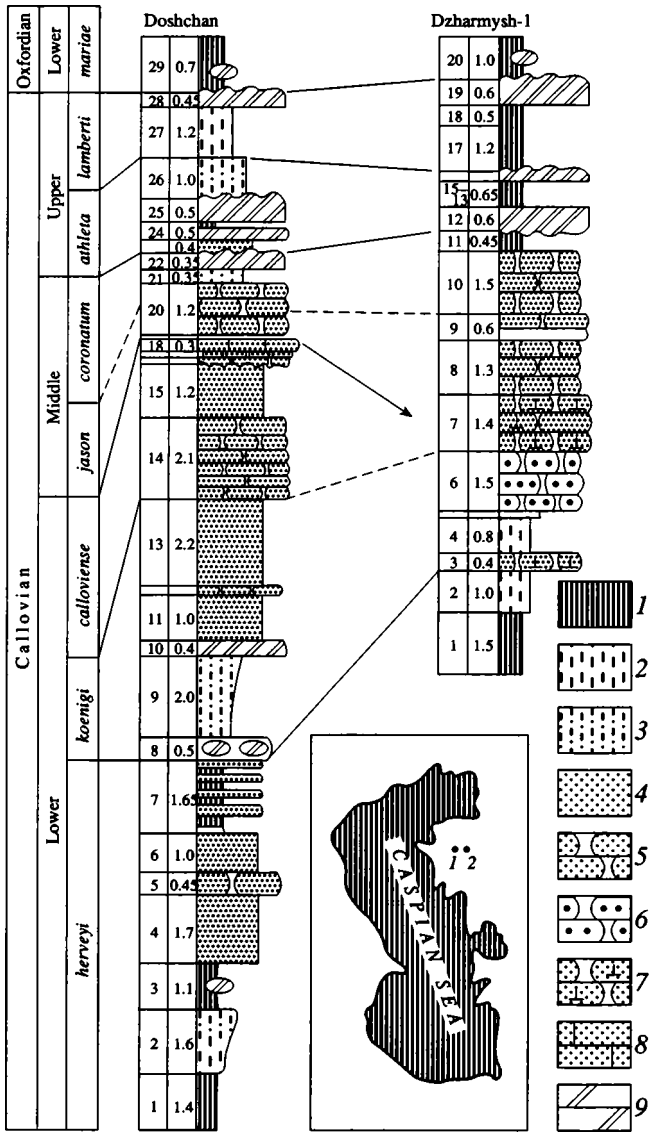


Fig. 1. Stratigraphic columns of Callovian–basal Oxfordian sections in Mangyshlak: (*1*) clay; (*2*) silty clay; (*3*) sandy clay; (*4*) fine-grained sand; (*5*) fine-grained sandstone; (*6*) medium-grained sandstone; (*7*) calcareous sandstone; (*8*) sandy limestone; (*9*) marl.

(14) Sandstone, greenish-gray, calcareous, locally grumous, with *Sigaloceras (Sigaloceras) calloviense* (Sow.), *S. (S.) khvalynicum* Repin et Rashwan, *S. (S.) trichophorum* (Buckman), *S. (S.) micans* Buckman, S. *(S.) explanatum* Repin, *Sigaloceras (Gulielmina) quinquiplicatum* Buckman, *S. (Gulielmina) mangischlakense* Sokolova, *S. (Gulielmina) filocostatum* Sokolova, *Proplanulites* cf. *koenigi* (Sow.), *P. fabricatus* Buckman, *P. krymholtzi* Repin et Rashwan, *P. arciruga inflatus* Repin, *P. majesticus kaspiensis* Repin, *Indosphinctes (Elatmites) lobatus* (Buckman), *Lunuloceras (Brightia)* aff. *pseudopunctatum* (Lahusen), and *Sigaloceras (Gulielmina) rarum* Repin near the top (2.1 m);

(15) Sand, greenish-gray, ferruginate, bearing *Sigaloceras (Sigaloceras) calloviense* (Sow.), *S. (Catasigaloceras) enodatum* (Nik.), and *S. (Gulielmina) filocostatum* Sokolova (1.2 m);

(16) Sandstone, greenish-gray, ferruginate at the base, bearing *Sigaloceras (Catasigaloceras) enodatum* (Nik.), *S. (Gulielmina) mangischlakense* Sokolova, *Kosmoceras (Gulielmiceras) gulielmii anterior* Brinkmann, and *Binatisphinctes (Okaites) rjasanensis* (Teisseyre) (0.3 m);

(17) Sandstone, highly calcareous, with *Kosmoceras (Zugokosmokeras)* cf. *andrussovi* Sokolova (0.2 m);

(18) Sandy limestone, light gray, with *Sigaloceras (Catasigaloceras) enodatum* (Nik.), *Kosmoceras (Gulielmiceras) gulielmii anterior* Brinkmann, and *Indosphinctes (Elatmites) elatmaensis* (Sasonov) (0.3 m);

(19) Sandstone, ferruginate, bearing abundant *Sigaloceras (Catasigaloceras) enodatum* (Nik.) in association with *Kosmoceras (Gulielmiceras) gulielmii anterior* Brinkmann, *Indosphinctes (Indosphinctes) mutatus* (Traut.), *Binatisphinctes (Okaites) rjasanensis* (Teisseyre), and *Proplanulites* sp. indet. (0.15 m);

(20) Sandstone, greenish-gray, enclosing clay and gypsum interbeds, and containing *Sigaloceras (Catasigaloceras) enodatum* (Nik.), *Kosmoceras (Gulielmites) jason* (Rein.), *Kosmoceras (Kosmoceras) sokolovae* Rashwan, *K. (K.)* cf. *pollucinum* Teisseyre, *K. (Spinikosmokeras)* cf. *herakles* Tintant, *K. (S.) castor* (Rein.), *K. (Zugokosmokeras)* cf. *obductum* (Buckm.), *K. (Z.) obductum orientale* Repin, *K. (Gulielmiceras) gulielmii anterior* Brinkmann, *Lunuloceras (Lunuloceras) kaspiense* Repin, *Erymnoceras (Erymnoceras) coronatum* (Orb.), and *Indosphinctes (Indosphinctes)* sp. indet. (1.2 m);

(21) Clay, greenish-gray, sandy (0.35 m);

(22) Marl, yellowish-gray (0.35 m);

(23) Clayey sand, yellow-gray, with ferruginate nodules bearing *Peltoceras (Peltoceras) athleta* (Phillips), *P. (Parapeltoceras) pseudotorosum* Prieser, *P. (P.) baylei* Prieser, *P. (P.) tuarkyrensis* Aman., and *P. (P.) broilii* Prieser (0.4 m);

(24) Marl, gray, grading upward into gray calcareous clay with *Kosmoceras (Lobokosmokeras) proniae* Teisseyre, *Peltoceras (Peltoceras) athleta* (Phillips), *P. (Parapeltoceras) pseudotorosum* Prieser, and *P. (P.)* cf. *broilii* Prieser (0.5 m);

(25) Marl, greenish-gray (0.5 m);

(26) Gray sandy clay with abundant carbonate nodules (1.0 m);

(27) Gray silty clay (1.2 m);

(28) Marl, light yellow, containing *Quenstedtoceras (Quenstedtoceras) lamberti* (Sow.), *Q. (Q.) flexicostatum* (Phillips), *Q. (Q.) subflexicostatum* Sinzow, *Kosmoceras (Kosmoceras) spinosum* (Sow.), *K. (K.) duncani* (Sow.), *K. (K.)* cf. *transitionis* (Nik.), and *K. (Zugokosmokeras)* cf. *theodori* (Opp.) (0.45 m);

(29) Clay, yellowish-gray, with abundant ferruginate nodules and ammonites, such as *Cardioceras (Scarburgiceras) praecordatum* Douv., *Vertumniceras* cf. *mariae* (Orb.), *V. mangischlakense* Repin et Rashwan, *Aspidoceras* cf. *perarmatum* (Sow.), *Peltoceras (Parawedekindia) arduennense* (Orb.), *Oppelia* ex gr. *sublevipicta* Sinzow, and *Creniceras* sp. (0.3–1.1 m).

In this section, beds 1–17 are assigned to the lower Callovian, although with respect to beds 1–7, this statement is merely conditional. Two units comprising beds 8–13 and 14–19 correspond to the *Proplanulites koenigi* and *Sigaloceras calloviense* zones, respectively.

The entire range of the middle Callovian is represented by Bed 20 presumably together with beds 21 and 22.

Beds 23–28 are of the late Callovian age. Among them, beds 23 and 24 definitely mark the *Peltoceras athleta* Zone, and Bed 28 corresponds to the *Quenstedtoceras lamberti* Zone. Bed 29 is referred to the lower Oxfordian *Vertumniceras mariae* Zone.

Dzharmysh-1 Section

The section is 1.2 km eastward of the previous one (Fig. 1), and comprises the following beds:

(1) Clay, brown-gray, dense, thin-platty, with silt admixture (1.5 m);

(2) Clay, gray, medium-platty, enclosing ferruginate interbeds with jarosite (1.0 m);

(3) Sandstone, fine-grained, coaly-calcareous, with gypsum and flat limestone concretions, which yielded *Proplanulites* cf. *koenigi* (Sow.), *P. fabricatus* Buckman, *P. arciruga inflatus* Repin, *Kepplerites (Gowericeras) gowerianus* (Sow.), *K. (Toricellites) hexagonus* (Loewe), and *Chamoussetia chamousseti* (Orb.) (0.4 m);

(4) Siltstone, gray, ferruginate, clayey (0.8 m);

(5) Siltstone, gray, clayey-sandy (0.2 m);

(6) Sandstone, medium-grained, poorly consolidated and vaguely laminated (1.5 m);

(7) Sandstone, gray, fine-grained, coarsely laminated, bearing *Phylloceras* sp. indet., *Kepplerites (Toricellites) approximatus* Buckman, *Sigaloceras (Sigaloceras) calloviense* (Sow.), *S. (S.) khvalynicum* Repin et Rashwan, *S. (S.) trichophorum* (Buckman), *S. (S.) explanatum* Repin, *S. (Catasigaloceras) enodatum* (Nik.), *S. (C.) planicerclus* (Buckman), *S. (Gulielmina) filocostatum* Sok., *Kosmoceras (Gulielmiceras) gulielmii anterior* Brinkmann, *K. (Gulielmites) jason* (Rein.), *K. (G.)* cf. *medea* Call., *Pseudocadoceras petelini* (Pomp.), *Indosphinctes (Indosphinctes) mutatus* (Traut.), *I. (I.) choffati dualis* Repin, *I. (Elatmites) elatmaensis* Sasonov, and Oppeliidae gen. et sp. indet. (1.4 m);

(8) Sandstone, greenish-gray, ferruginate, with dense calcareous interbeds and single specimens of *Indosphinctes (Indosphinctes) mutatus* (Traut.) (1.3 m);

(9) Sandstone as described in Bed 7, containing *Sigaloceras (Gulielmina) quinquiplicatum* Buckman, *Kosmoceras (Gulielmites) jason* (Rein.), *Indosphinctes (Indosphinctes) mutatus* (Traut.), *Choffatia (Grossouvria)* cf. *variabilis* (Lahusen), and *Lunuloceras (Lunuloceras) kaspiense* Repin (0.5–0.7 m);

(10) Sandstone similar to that in Bed 8, bearing *Erymnoceras (Erymnoceras) coronatum* (Orb.), *Indosphinctes (Elatmites)* sp. indet., and *Kosmoceras (Zugokosmokeras) obductum orientale* Repin (1.5 m);

(11) Clay, brown-gray, thin-platty, silty, with *Kosmoceras* sp. indet. (0.45 m);

(12) Marl, light gray, massive, with remains of *Kosmoceras (Lobokosmokeras) proniae* Teiss., *K. (L.) rowlstonense* (Y. et B.), *Peltoceras (Peltoceras) athleta* (Phill.), *P. (Parapeltoceras) russiense* Sinzow, *P. (P.) tuarkyrense* Aman., and *P. (P.) broilii* Prieser (0.6 m);

(13) Clay, gray, silty-calcareous, with oval marl concretions; the bed yielded *Kosmoceras (Kosmoceras) spinosum* (Sow.), *K. (K.) transitionis* (Nik.), and *Lunuloceras (Brightia) nodosum* Bonar. (0.25 m);

(14) Clay, bright yellow, silty, small-rubble, with jarosite (0.15 m);

(15) Clay as described in Bed 14 (0.25 m);

(16) Marl, gray, clayey (0.1 m);

(17) Clay, gray, calcareous, containing *Quenstedtoceras (Quenstedtoceras) flexicostatum* (Phill.), and *Kosmoceras (Kosmoceras) spinosum* (Sow.) (0.5 m);

(18) Clay, ocherous, calcareous (0.5 m);

(19) Marl, light gray, with *Quenstedtoceras (Quenstedtoceras) lamberti* (Sow.), *Q. (Q.) subflexicostatum* Sinzow, *Kosmoceras (Kosmoceras) spinosum* (Sow.), *K. (K.) duncani* (Sow.), *Peltoceras (Parapeltoceras) russiense* Sinzow, and *Lunuloceras (Brightia) pseudopunctatum* (Lahusen) (0.6 m);

(20) Clay, greenish-gray, platty, calcareous, with light-gray massive marl nodules and ammonite remains: *Vertumniceras* cf. *mariae* (Orb.), *V. mangischlakense* Repin et Rashwan, *Cardioceras (Scarburgiceras) praecordatum* Douv., *Peltoceras (Peltoceras)* cf. *eugenii* Raspail, *P. (Peltoceratoides) constantii* Orb., and *Oppelia* ex gr. *sublevipicta* Sinzow (0.3 m);

The lower Callovian interval in this section comprises beds 1–6, among which Bed 3 is definitely correlative with the *Proplanulites koenigi* Zone. Bed 7 yielded the mixed ammonite assemblage corresponding to the *Sigaloceras calloviense* and *Kosmoceras jason* zones of the lower and middle Callovian, respectively. Beds 8 and 9 represent the *Kosmoceras jason* Zone, while Bed 10 is an equivalent of the *Erymnoceras coronatum* Zone of the middle Callovian. The upper Callovian begins with Bed 12, which yielded ammonites of the *Peltoceras athleta* Zone. The ammonite assemblage typical of the uppermost *Quenstedtoceras lamberti* Zone was identified in beds 17–19. Bed 20 marks the *Vertumniceras mariae* Zone of the basal Oxfordian.

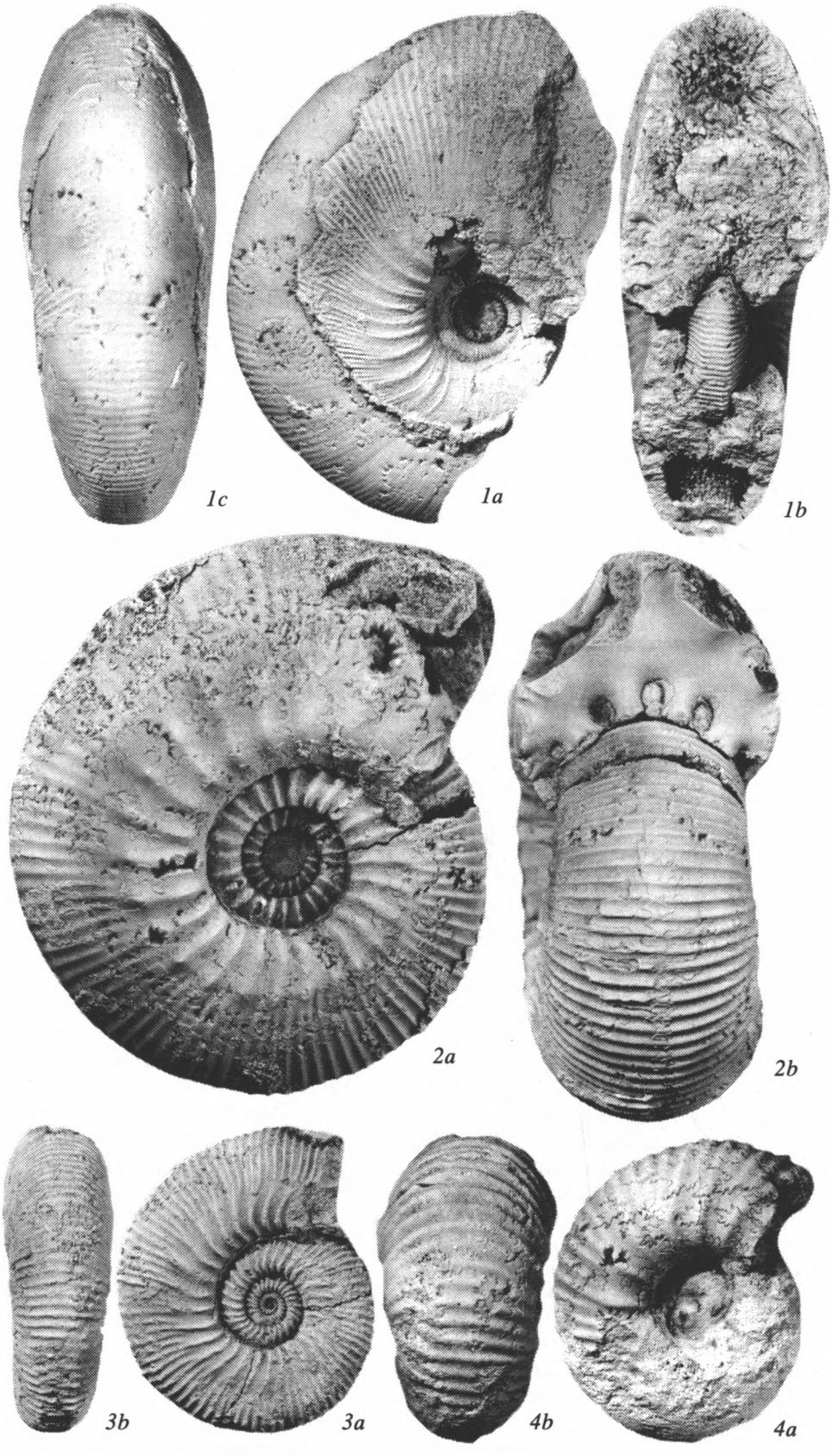

1c
1a
1b
2a
2b
3b
3a
4b
4a

Table 1. Callovian ammonite levels in Mangyshlak

Stage	Substage	Standard units		Mangyshlak	
		Zone	Subzone	Zone	Subzone
Oxfordian	Lower	*Vertumniceras mariae*	*Cardioceras (Scarburgiceras) praecordatum*	*mariae*	*praecordatum*
			Cardioceras (Scarb.) scaeburgense		?
Callovian	upper	*Quenstedtoceras lamberti*	*Quenstedtoceras lamberti*	*lamberti*	*lamberti*
			Quenstedtoceras henrici		?
		Peltoceras athleta	*Kosmoceras (Kosmoceras) spinosum*	*athleta*	*spinosum*
			K. (Lobokosmokeras) proniae		*proniae*
			K. (Lobokosmokeras) phaeinum		?
	middle	*Erymnoceras coronatum*	*K. (Zugokosmokeras) grossouvrei*	*coronatum*	?
			K. (Zugokosmokeras) obductum		*obductum*
		Kosmoceras jason	*K. (Gulielmites) jason*	*jason*	*jason*
			K. (Gulielmites) medea		*medea*?
	lower	*Sigaloceras calloviense*	*Sigaloceras (Catasigaloceras) enodatum*	*calloviense*	*enodatum*
			S. (Sigaloceras) calloviense		*calloviense*
		Proplanulites koenigi	*Kepplerites (Kepplerites) galilaei*	*koenigi*	?
			K. (Kepplerites) curtilobus		*curtilobus*
			K. (Gowericeras) gowerianus		*gowerianus*
		Macrocephalites herveyi	*M. (Kamptokephalites) kamptus*	?	
			M. (Macrocephalites) terebratus		
			Kepplerites (Kepplerrites) keppleri		

CALLOVIAN BIOZONATION OF MANGYSHLAK

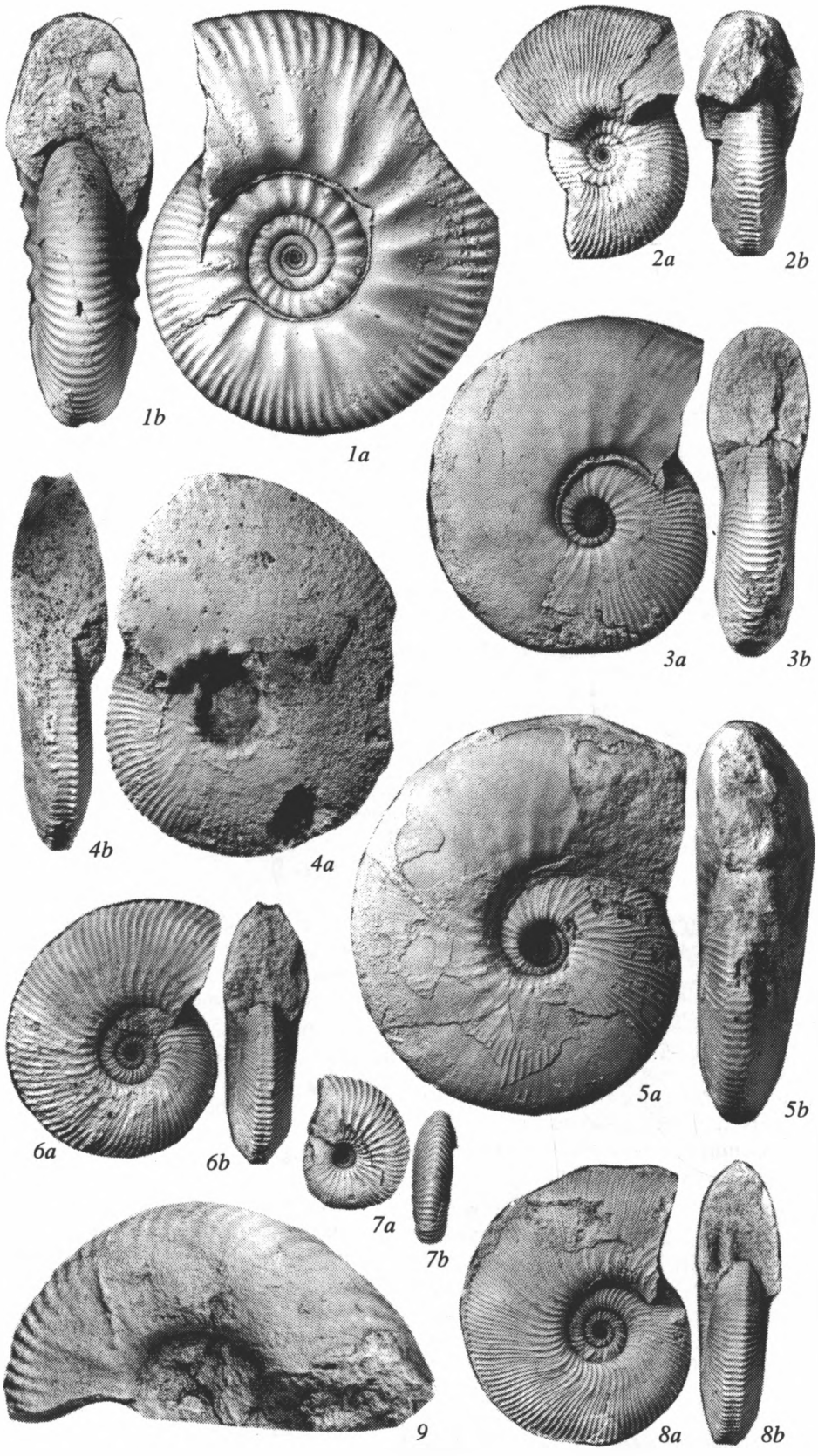
In 1950, Sokolova was the first to subdivide the Callovian deposits of Mangyshlak into substages and zones. The respective stratigraphic scheme suggested the lower substage to be corresponding to the *Macrocephalites macrocephalus* Zone, the middle substage to be comprising two units, namely the *Kosmoceras jason* and *Stephanoceras coronatum* zones, and the upper one to be spanning the *Peltoceras athleta* Zone.

Later, Savel'ev (1963) divided the lower substage into *M. macrocephalus* and *Sigaloceras calloviense* zones analogous to these units of the Callovian zonation in northwestern Europe. However, this researcher did not indicate pertinent zonal assemblages, but simply cited the list of early Callovian ammonites as it was identified by Sokolova (1950).

The middle Callovian in this later scheme consisted of two units, the *Kosmoceras jason* and *Erymnoceras coronatum* zones. In addition to the *Peltoceras athleta* Zone, the upper substage was thought to be comprising one more unit marked by two index species: *Quenstedtoceras mariae* and *Q. lamberti*. The lower Oxfordian deposits in the section were distinguished by Savel'ev at the occurrence level of *Cardioceras cordatum* (Sow.), *C. vertebrale* (Sow.), and *Peltoceras (Parawedekindia) arduennense* (Orb.).

Afterwards, Savel'ev *et al.* (1973) proposed to consider the lower Callovian of Mangyshlak as corresponding to one biozone of three index species—*Macrocephalites macrocephalus, Kepplerites gowerianus*, and *Kepplerites calloviense*—because their vertical distribution was insufficiently understood. They also interpreted the uppermost Callovian zone as

Plate I. Characteristic Callovian ammonite species from Mangyshlak (full-size).
(*1*) *Sigaloceras (Sigaloceras) calloviense* (Sowerby), no. 847/248, Dzharmysh-1, Bed 7, the *calloviense* Zone; (*2*) *Kepplerites (Gowericeras) gowerianus* (Sowerby), no. 847/261, Mt. Sary-Diirmen', Bed 3, the *koenigi* Zone; (*3*) *Kepplerites (Toricellites) hexagonus* (Loewe), no. 847/260, Doshchan, Bed 12, the *koenigi* Zone; (*4*) *Erymnoceras (Erymnoceras) coronatum* (Orbigny), no. 847/221, Dzharmysh-3, upper part of the Bed 9, the *coronatum* Zone.


1b
1a
2a
2b
3a
3b
4b
4a
5a
5b
6a
6b
7a
7b
9
8a
8b

marked by only one index species *Quenstedtoceras lamberti*. In subsequent studies on the Callovian biozonation in Mangyshlak, this scheme was considered as basically valid.

The standard biozonation of the Callovian and basal Oxfordian was suggested by English researchers. In their comments on the standard scheme, S.V. Meledina and M.S. Mesezhnikov (*Zony* ..., 1982) proposed some modifications concerning only the zonal and subzonal units of the lower Callovian. These proposals were based on data of German and English paleontologists, who studied the lower Callovian biozonation in detail and suggested some changes in its nomenclature (Callomon *et al.*, 1987, 1989). As a matter of fact, the revised distribution of topotype *Macrocephalites macrocephalus* (Schlotheim) in the Schwabian sections has demonstrated that this index species occurs not in the lowermost Callovian zone, but in the next unit overlying it.

Thus, *Macrocephalites herveyi* was once again admitted to be the index species of the lowermost Callovian zone, as was first suggested by Spath. Bringing back the biozonation scheme of Buckman and Spath, Callomon *et al.* (1987) accepted the three-member subdivision of the lower Callovian. They also substantiated the idea that a discrete and geographically widespread stratigraphic level with *Kepplerites (Kepplerites) keppleri* corresponds to the basal subzone of the Callovian. Other subzonal units of this stage are shown in Table 1.

All genera and many species of ammonites, which have been distinguished in the Callovian and basal Oxfordian deposits of Mangyshlak, are of the subboreal type, displaying wide geographic ranges. Accordingly, among them there are many forms in common with ammonite assemblages from Mangyshlak and Western Europe, and this is very favorable for the direct correlation with the standard scale. In such a way, the latter can be used for the detailed biozonation of local sections (Plates I–III).

Integrated data on ammonite distribution in studied sections suggest the following scheme of sequential ammonite levels (Table 1).

Lower Callovian

In Mangyshlak, where the uppermost Bathonian and basal Callovian zones are disjointed, the lower boundary of the latter has never been depicted by using paleontological remains. The interval in question is barren of ammonites, and the boundary is conditionally drawn on the basis of lithologic data.

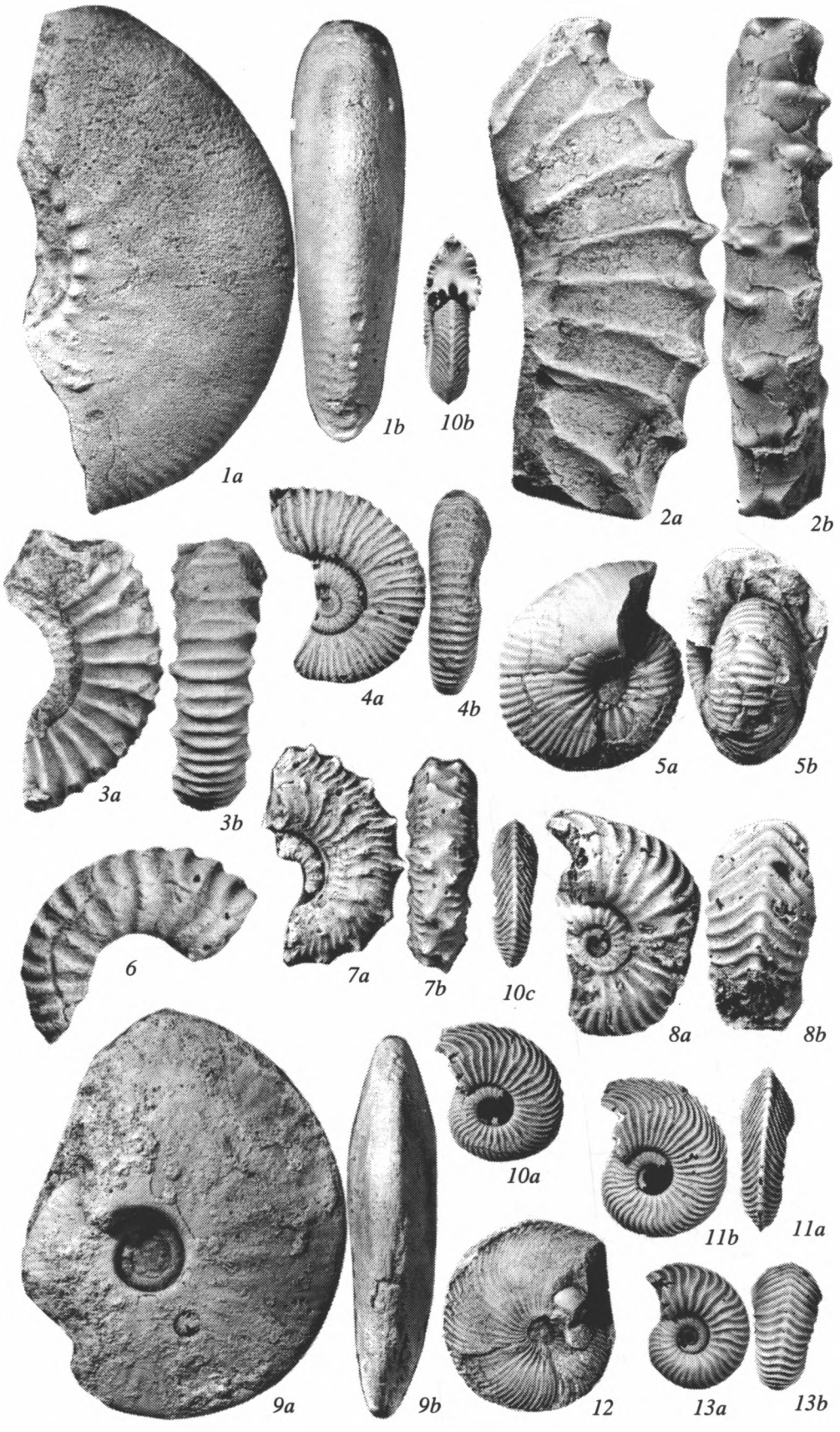
Table 2. Abundance parameters of Callovian ammonites from Mangyshlak

Family	Lower Callovian (%)	Middle Callovian (%)	Upper Callovian (%)	Total	
				Genera/species	%
Cardioceratidae	3.3	4	20	3/6	8.4
Kosmoceratidae	53	40	35	3/30	41.8
Macrocephalitidae	6.6	–	–	1/2	2.8
Perisphinctidae	33	24	–	5/16	22.2
Pachyceratidae	–	8	–	1/2	2.8
Oppeliidae	3.3	16	15	2/8	11.0
Aspidoceratidae	–	4	30	1/7	9.6
Phylloceratidae	–	4	–	1/1	1.4
				17/72	100.0

The *Proplanulites koenigi* Zone (Bed 3 of the Dzharmysh-1 and beds 8–12 of the Doshchan sections) is the lowermost unit of the Callovian zonation authenticated from the viewpoint of paleontology. In the studied sections, the basal *Macrocephalites herveyi* Zone of the Callovian is imperceptible. Pointing to the presence of *Macrocephalites tumidus* (Rein.) and *M. macrocephalus* (Schloth.), Sokolova did not picture or describe them, and did not provide data on the exact locality and stratigraphic position of these fossils. At the same time, *Macrocephalites* forms from our collection [*M. (Pleurocephalites)* cf. *pila* (Nik.) and *M. (Kamptokephalites)* sp. from Bed 10, the Doshchan section] occur together with ammonites of the *Proplanulites koenigi* Zone.

Nevertheless, there is still a chance to distinguish the *Macrocephalites herveyi* Zone or its analogues below the *koenigi* Zone in other sections, i.e., to establish stratigraphic relations typical of the Callovian stratotype. At the same time, it would be against the factual data to consider the *M. macrocephalus*, or integrated *M. macrocephalus–K. gowerianus–S. calloviense* zones (Savel'ev, 1963 and Savel'ev *et al.*, 1973, respectively) as corresponding to the entire range of the lower Callovian. Thus, at present, the lower Callovian of Mangy-

Plate II. Characteristic Callovian ammonite species (full size).
(*1*) *Proplanulites krymholtzi* Repin et Rashwan, no. 847/267, Doshchan, Bed 14, the *koenigi* Zone; (*2*) *Sigaloceras (Gulielmina) mangischlakense* Sokolova, no. 847/316, Doshchan, Bed 14, the *calloviense* Zone; (*3* and *5*) *Sigaloceras (Catasigaloceras) enodatum* (Nikitin), no. 847/323, Doshchan, Bed 15, and no. 847/274, Doshchan, Bed 19, the *enodatum* Subzone; (*4*) *Kosmoceras (Gulielmites) jason* (Reinecke), no. 847/53, Dzharmysh-3, Bed 9, the *jason* Zone; (*6*) *Sigaloceras (Gulielmina) filocostatum* Sokolova, no. 847/319, neotype, Doshchan, Bed 14, the *calloviense* Zone and Subzone; (*7*) *Pseudocadoceras petelini* (Pomp.), no. 847/88, Dzharmysh-1, Bed 7, the *calloviense–jason* zones; (*8*) *Sigaloceras (Gulielmina) quinqueplicatum* Buckman, no. 847/310, Doshchan, Bed 14, the *calloviense* Zone and Subzone; (*9*) *Quenstedtoceras (Quenstedtoceras) lamberti* (Sowerby), no. 847/159, Dzharmysh-1, Bed 19, the *lamberti* Zone.


1a
1b
10b
2a
2b
3a
3b
4a
4b
5a
5b
6
7a
7b
10c
8a
8b
9a
9b
10a
11b
11a
12
13a
13b

shlak definitely comprises two successive *Proplanulites koenigi* and *Sigaloceras calloviense* zones, while its interval corresponding to the standard *Macrocephalites herveyi* Zone is barren of ammonites.

Proplanulites koenigi Zone

In the Mangyshlak sections, the zonal assemblage includes *Kepplerites (Kepplerites) curtilobus* (Buckm.), *K. (Toricellites) approximatus* Buckm., *K. (T.) hexagonus* (Loewe), *K. (Gowericeras) gowerianus* (Sow.), *Proplanulites* cf. *koenigi* (Sow.), *P. teisseyrei* Tornq., *P. excentricus tenius* Repin, *P. arciruga inflatus* Repin, *Macrocephalites (Dolikephalites)* cf. *pila* (Nik.), *M. (Kamptokephalites)* sp., *Chamoussetia* ex gr. *chamousseti* (Orb.), and *Hecticoceras* sp. indet.

Among these forms, there are index species of two lower subzones, namely *K. (G.) gowerianus* and *K. (K.) curtilobus*; however, their stratigraphic ranges are not isolated in the sections.

Sigaloceras calloviense Zone

This zone yielded such forms as *Sigaloceras (Sigaloceras) calloviense* (Sow.), *S. (S.) khvalynicum* Repin et Rashwan, *S. (S.) trichophorum* (Buckm.), *S. (S.) explanatum* Repin, *S. (S.) micans* Buckm., *S. (Gulielmina) quinquiplicatum* Buckm., *S. (G.) mangischlakense* Sok., *S. (G.) filocostatum* Sok., *S. (G.) rarum* Repin, *S. (Catasigaloceras) enodatum* (Nik.), *S. (C.) planicerclus* Buckm., *Indosphinctes (Elatmites) elatmaensis* (Sasonov), ? *I. (E.) lobatus* (Buckm.), *Binatisphinctes (Okaites) rjasanensis* (Teisseyre), *Kosmoceras (Gulielmiceras) gulielmii anterior* Brinkm., *Proplanulites krymholtzi* Repin et Rashwan, *P. fabricatus* Buckm., *P.* cf. *koenigi* (Sow.), *P. majesticus kaspiensis* Repin, and *P. arciruga inflatus* Repin.

The assemblage includes index species of constituent subzones of the *S. calloviense* Zone. Different species of *Sigaloceras* s. str. are characteristic of the *S. calloviense* Subzone. In the *S. (C.) enodatum* Subzone, its index species associates with *Kosmoceras (Gulielmiceras) gulielmii anterior* Brinkm. and archaic representatives of the genus *Indosphinctes*.

Proplanulites species occurring in the lower part of the *S. calloviense* Zone somewhat deminish the discreteness of the *P. koenigi* Zone.

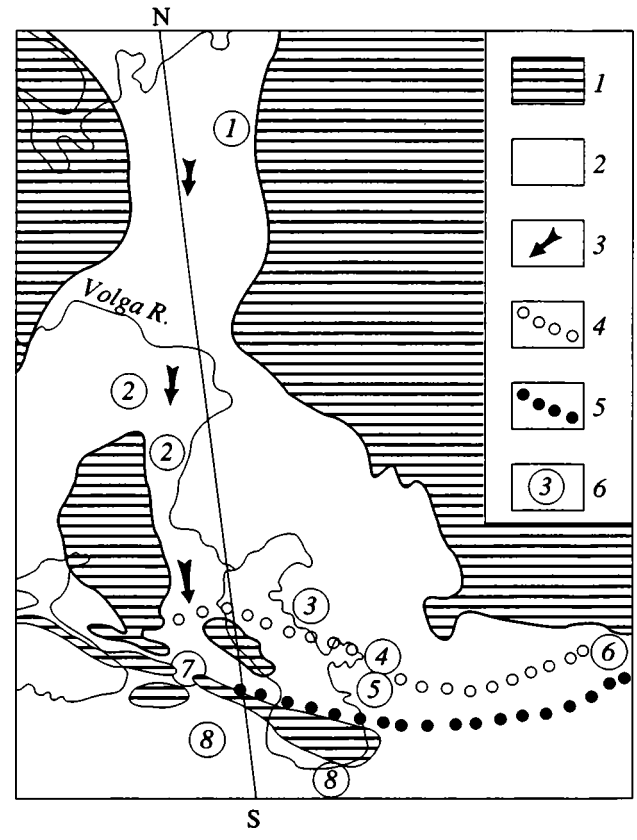


Fig. 2. Paleogeographic scheme of the Callovian: (1) land, contours from (*Paleogeografiya* ..., 1975); (2) sea; (3) main path of boreal ammonite migration (*Cadoceras* and other forms); (4) boundary between the Tethyan and Boreal belts (*Paleogeografiya* ..., 1975); (5) the same boundary according to our evaluation; (6) ammonite localities under comparison (*1*—Timan–Pechora province; *2*—Volga region; *3*—Mangyshlak; *4*—Tuarkyr; *5*—Bol'shoi Balkhan; *6*—Kugitang; *7*—Northern Caucasus; *8*—Northern Iran).

Middle Callovian

This interval in the Mangyshlak sections is represented by condensed beds up to 2–4 m in total thickness, and its zonation is evident only in particular localities (e.g., Dzharmysh-1). The composite assemblage of ammonites from this stratigraphic range includes zonal and some subzonal index species, such as *Kosmoceras (Kosmoceras) sokolovae* Rashwan, *K. (K.)* cf. *pollucinum* Teisseyre, *K. (Gulielmites) jason* (Rein.), *K. (G.)* cf. *medea* Cal., *K. (Spinikosmokeras) castor*

Plate III. Characteristic Callovian ammonite species.
(*1*) *Kosmoceras (Gulielmites) medea* Callomon, no. 847/49, Dzharmysh-1, Bed 7, the *jason* Zone; (*2*) *Peltoceras (Peltoceras) eugenii* (Raspail), no. 847/256, Doshchan, Bed 29, the *mariae* Zone; (*3*) *Peltoceras (Peltoceras) athleta* (Phill.), no. 847/266, Dzharmysh-1, Bed 12, the *athleta* Zone; (*4*) *Peltoceras (Parapeltoceras) arduennense* (Orbigny), no. 847/264, Doshchan, Bed 29, the *mariae* Zone; (*5*) *Macrocephalites (Pleurocephalites)* cf. *pila* (Nikitin), no. 847/624, Doshchan, Bed 12, the *koenigi* Zone; (*6*) *Vertumniceras mariae* Orbigny, no. 847/265, Doshchan, Bed 29, the *mariae* Zone; (*7*) *Kosmoceras (Kosmoceras) spinosum* (Sowerby), no. 847/272, Dzharmysh-1, Bed 12, the *athleta* Zone; (*8* and *13*) *Vertumniceras mangischlakense* Repin et Rashwan: (*8*) no. 847/251, Dzharmysh-3, Bed 18, and (*13*) no. 847/256, holotype, Dzharmysh-3, Bed 18, the *mariae* Zone; (*9*) *Lunuloceras (Lunuloceras) kaspiense* Repin, 847/116, holotype, Dzharmysh-3, Bed 9, middle Callovian; (*10* and *11*) *Cardioceras (Scarburgiceras) praecordatum* Douv., no. 847/625, Dzharmysh-3, Bed 18, the *mariae* Zone, and no. 847/6, Doshchan, Bed 29, the *mariae* Zone; (*12*) *Chamoussetia* ex gr. *chamousseti* (Orb.), no. 847/628, Doshchan, Bed 10, the *koenigi* Zone.

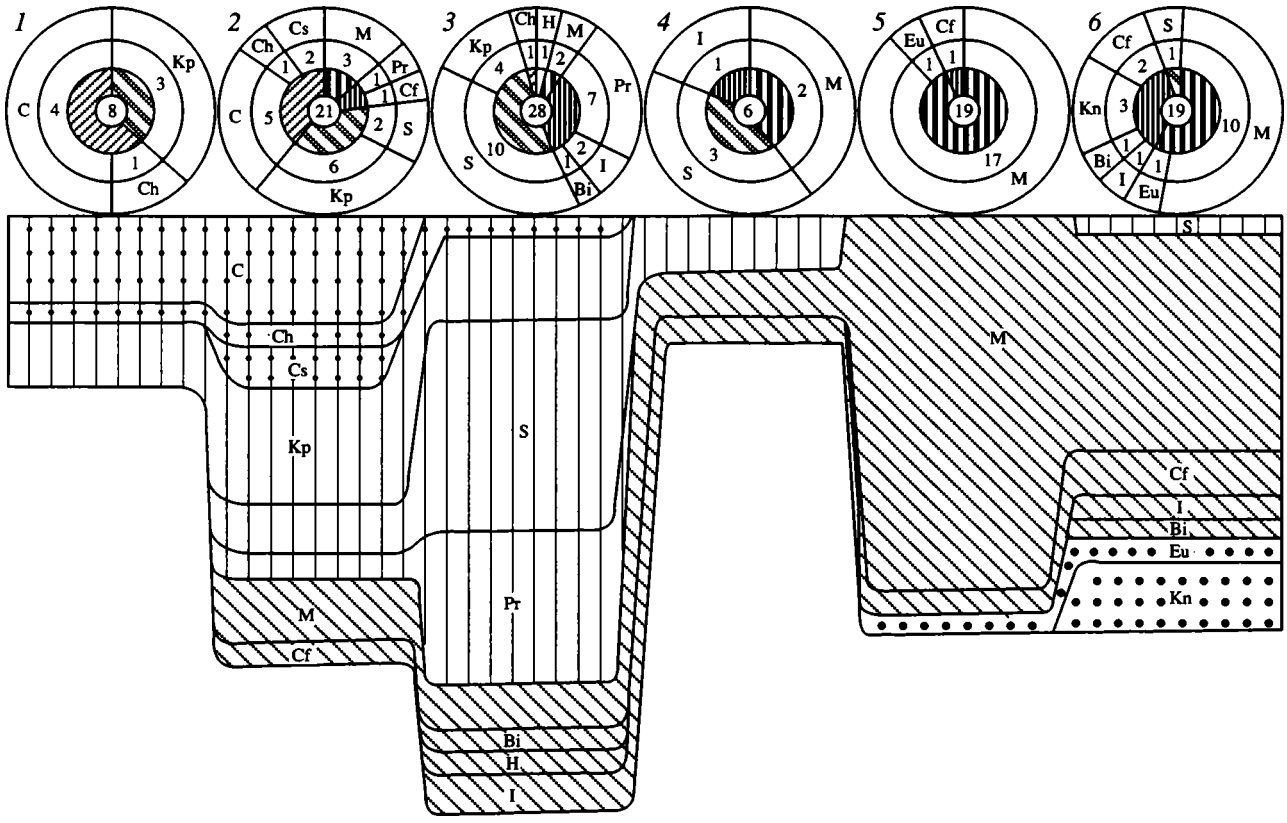


Fig. 3. Chorologic profile for the early Callovian substage (symbols as indicated in Fig. 4).

(Rein.), *K. (S.)* cf. *herakles* Tintant, *K. (Zugokosmokeras)* cf. *obductum* (Buckm.), *K. (Z.) obductum orientale* Repin, *K. (Gulielmiceras) gulielmii anterior* Brinkmann, *Sigaloceras (Catasigaloceras) enodatum* (Nik.), *Indosphinctes (Indosphinctes) mutatus* (Traut.), *I. (I.) choffati dualis* Repin, *I. (Elatmites) elatmaensis* (Sasonov), *Pseudocadoceras petelini* (Pomp.), *Lunuloceras (Lunuloceras) kaspiense* Repin, *Erymnoceras (Erymnoceras) coronatum* (Orb.), and *Choffatia (Grossouvria)* cf. *variabilis* (Lahusen).

The stratigraphic range of *Sigaloceras (Catasigaloceras) enodatum* (Nik.) is very remarkable. In the Doshchan section, this species occurs within a discrete interval above the *S. calloviense* Subzone and at the base of the middle Callovian. In this basal bed, it is in association with *K. (Gulielmites) jason* (Rein.).

Upper Callovian

This substage begins with the *Peltoceras athleta* Zone. Its assemblage is represented by *Peltoceras (Peltoceras) athleta* (Phill.), *P. (Parapeltoceras) pseudotorosum* Prieser, *P. (P.) baylei* Prieser, *P. (P.) tuarkyrense* Aman., *P. (P.) broilii* Prieser, *P. (P.) russiense* Sinzow, *Kosmoceras (Lobokosmokeras) proniae* Teiss., *K. (L.) rowlstonense* (Y. et B.), *Kosmoceras (Kosmoceras) spinosum* (Sow.), *K. (K.) transitionis* (Nik.), *Lunuloceras (Brightia) nodosum* Bonar., and *Hecticoceras (Hecticoceras) glyptum* Buckm.

The zone most likely includes all three subzones. Index species of two upper subzones (*K. proniae* and *K. spinosum*) have actually been distinguished in the studied sections. The basal *K. phaeinum* Subzone appears to be present, because such species as *K. proniae* occurs only in the middle part of the interval, which yielded the ammonites listed above.

The *Quenstedtoceras lamberti* Zone contains the following ammonite species: *Quenstedtoceras (Quenstedtoceras) lamberti* (Sow.), *Q. (Q.) flexicostatum* (Phill.), *Kosmoceras (Kosmoceras) spinosum* (Sow.), *K. (K.) duncani* (Sow.), *K. (K.) transitionis* (Nik.), *K. (Zugokosmokeras)* cf. *theodorii* (Opp.), *Peltoceras (Parapeltoceras) russiense* Sinzow, and *Lunuloceras (Brightia) pseudopunctatum* (Lahusen).

In the studied Mangyshlak sections, subzonal units of this zone are indistinct. Most likely, only the upper one (= *lamberti* Subzone) is fossiliferous here.

Lower Oxfordian

In addition to the index species, the *Vertumniceras mariae* Zone yielded *Cardioceras (Scarburgiceras) praecordatum* Douv., *Vertumniceras mangischlakense* Repin et Rashwan, *Aspidoceras* cf. *perarmatum* (Sow.), *Peltoceras (Peltoceras)* cf. *eugenii* Raspail, *P. (Peltoceratoides) constantii* Orb., *P. (Parawedekindia) arduennense* (Orb.), *Oppelia* ex gr. *sublevipicta* Sinzow, and *Creniceras* sp.

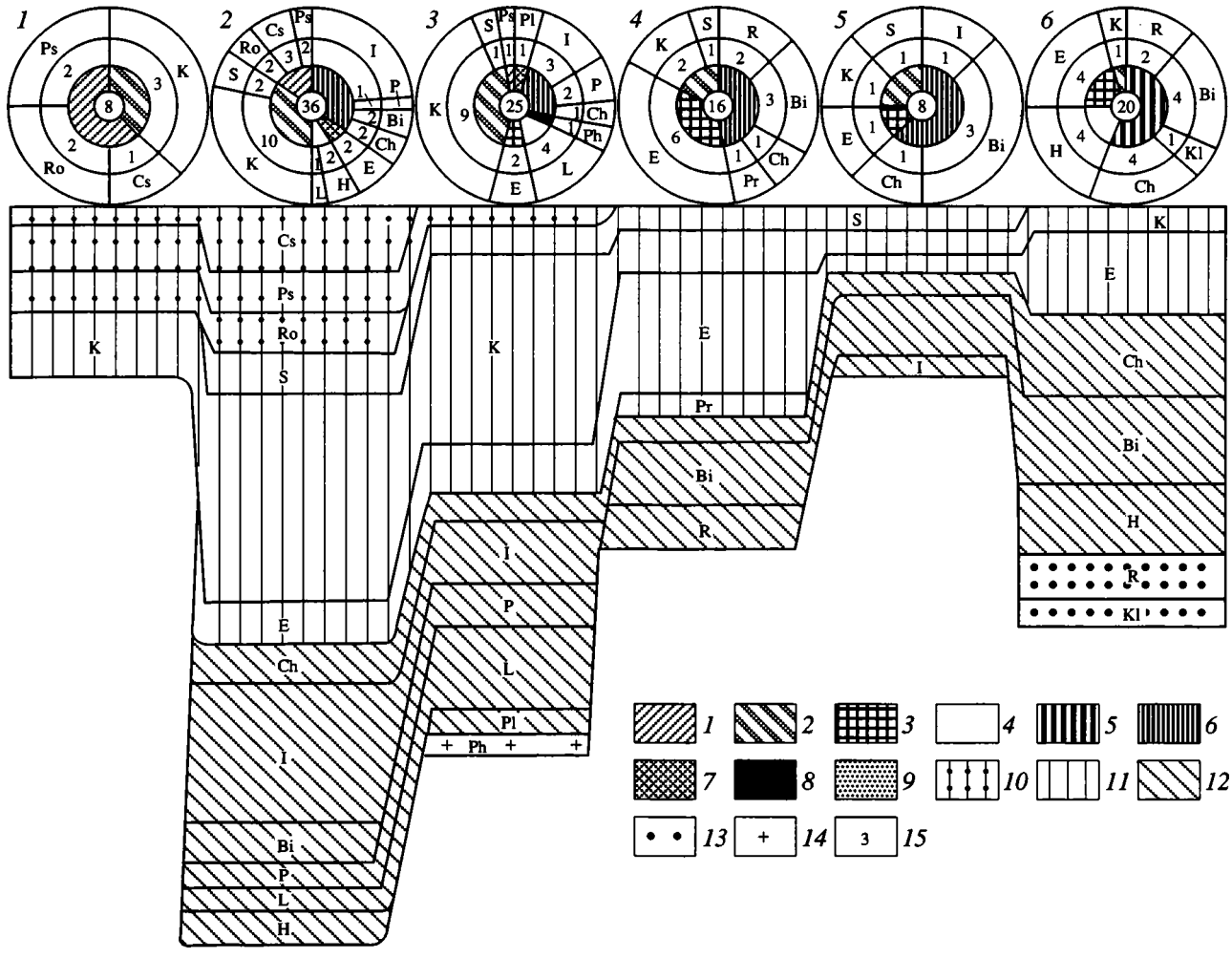


Fig. 4. Chorologic profile for the middle Callovian substage. Circles illustrate the structure of ammonite assemblages, for which generic indices and number of respective species are shown in two outer rings (figures in the center show total number of species): (C) *Cadoceras*, (Ch) *Chamoussetia*, (Kp) *Kepplerites*, (M) *Macrocephalites*, (Cs) *Costacadoceras*, (Cf) *Choffatia*, (Pr) *Proplanulites*, (S) *Sigaloceras*, (I) *Indosphinctes*, (Bi) *Binatisphinctes*, (H) *Hecticoceras*, (Eu) *Eucycloceras*, (Kn) *Kinkeliniceras*, (Ps) *Pseudocadoceras*, (K) *Kosmoceras*, (L) *Lunuloceras*, (P) *Properisphinctes*, (Ro) *Rondiceras*, (E) *Erymnoceras*, (Pl) *Peltoceras*, (Ph) *Phylloceras*, (R) *Reineckeia*, (Kl) *Klematosphinctes*, (Eb) *Eboraciceras*, (St) *Stenocadoceras*, (Ln) *Longaeviceras*, (Q) *Quenstedtoceras*, (Pv) *Pavloviceras*, (A) *Aspidoceras*, (Sw) *Sowerbiceras*, (V) *Valentolytoceras*, (O) *Orionoides*, (Sb) *Subgrossouvria*, (G) *Grossouvria*, (Ob) *Obtusicostites*, (Al) *Alligaticeras*, (Or) *Orbigniceras*, (Es) *Euaspidoceras*, (Hl) *Holcophylloceras*. Key to other symbols: (1–9) families: Cardioceratidae (*1*), Kosmoceratidae (*2*), Pachyceratidae (*3*), Oppeliidae (*4*), Macrocephalitidae (*5*), Perisphinctidae (*6*), Aspidoceratidae (*7*), Phylloceratidae (*8*), and Lytoceratidae (*9*); (*10–14*) chorologic types: boreal (*10*), subboreal (*11*), Tethyan-subboreal (*12*), Tethyan (*13*), and pandemic (*14*); (*15*) numbers of diagrams corresponding to locality numbers shown in Fig. 2.

This zone is presumably represented by its upper *C. praecordatum* Subzone, whose index species is very abundant in the lower Oxfordian deposits. Therefore, we may assume a hiatus in sedimentation corresponding to the *C. scarburgense* Subzone of the lower Oxfordian.

CHOROLOGY OF CALLOVIAN AMMONITES FROM MANGYSHLAK

Our study on Callovian ammonites from Mangyshlak affords an opportunity to revise the ecological structure and types of their assemblages, and to elucidate respective changes during this stage.

We estimated that the Callovian ammonite community of Mangyshlak included 72 species of 17 genera and eight families (Table 2). Among them, dominant taxa are represented by *Kepplerites, Sigaloceras*, and *Kosmoceras* genera of the Kosmoceratidae family, which were widespread in subboreal paleozoochores. Nearly half as many forms represent the family Perisphictidae, namely its subboreal *Proplanulites* (dominant) and Tethyan-subboreal *Indosphinctes* genera.

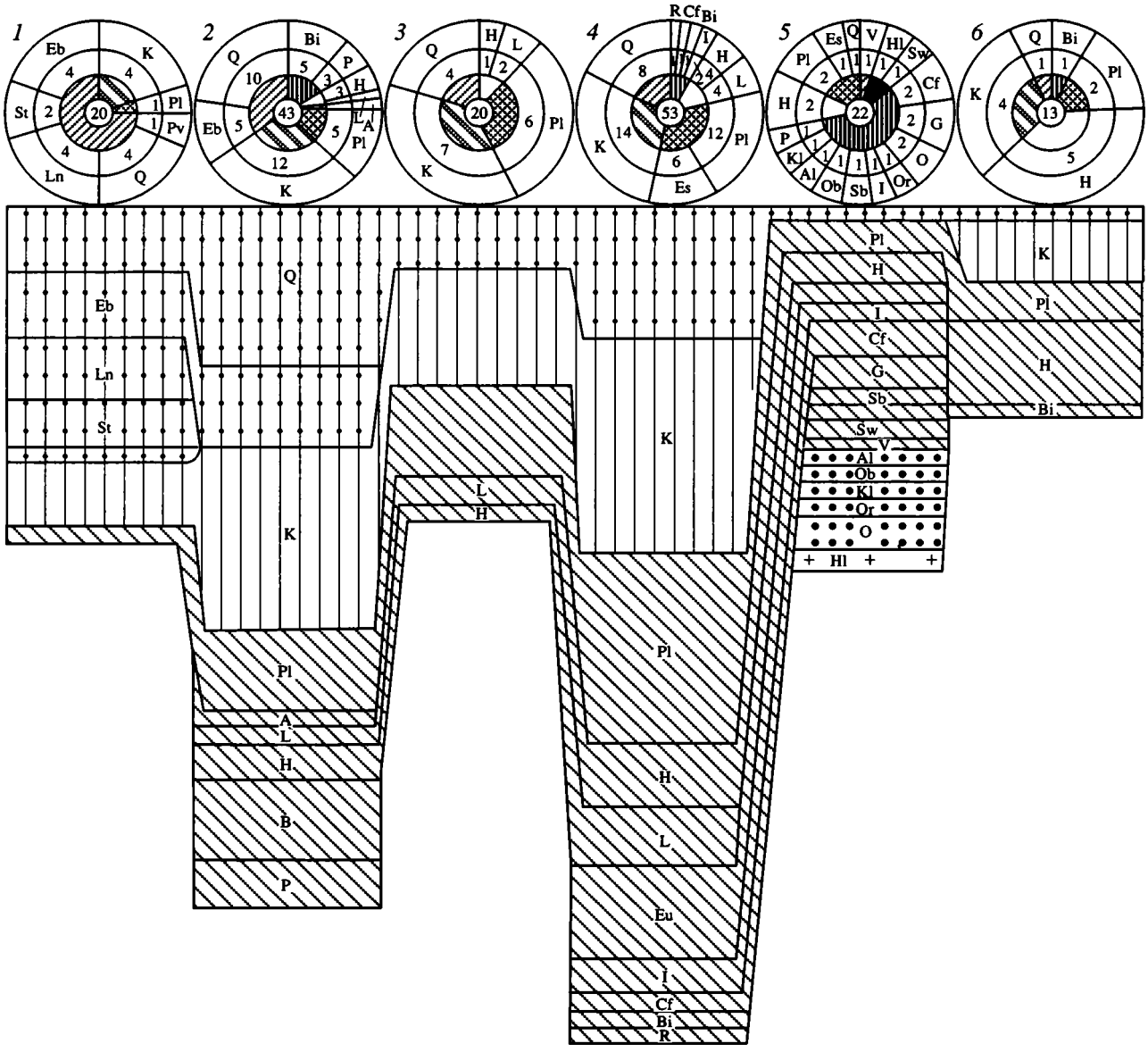


Fig. 5. Chorologic profile for the late Callovian substage (symbols as indicated in Fig. 4).

The Oppeliidae, Aspidoceratidae, and Cardioceratidae families are of lesser significance, and include from six to eight species. Other families show only one or two representatives.

From the viewpoint of biogeography, the studied fauna mostly consisted of subboreal taxa and less abundant Tethyan-subboreal elements. Legitimate Tethyan forms were absent, and only rare *Pseudocadoceras* species represented high-latitudinal boreal ammonites. Thus, in general, the Callovian ammonite community of Mangyshlak was similar to that of northwestern Europe, and definitely consisted of representatives of the subboreal paleozoochore.

The comparative analysis of ammonite assemblages from Mangyshlak and nearby regions showed the character of chorologic changes along the meridional profile from the Pechora River on the north to the Kugitang Ridge on the south (Figs. 2–5). To depict this, we used data on ammonite assemblages from the Pechora River basin (Keyserling, 1846; *Stratigrafiya* ..., 1976; Meledina, 1977, 1987), central Russian platform (Nikitin, 1881, 1885; Meledina, 1987; Kamysheva-Elpat'evskaya *et al.*, 1959; Sazonov, 1957, 1965; Alekseev *et al.*, 1986), Mangyshlak (Sokolova, 1950; Repin *et al.*, 1991), and Tuarkyr, Bol'shoi Balkhan, and Kugitang ranges (Amanniyazov, 1962, 1971).

In general, changes in composition along the studied profile and chorologic features of Callovian ammonites are gradual, i.e., consistent with the abstractions of Spath (1932) and Bodylevskii (1957). Trends of taxonomic diversity are less regular than those suggested by the theory (Stehli *et al.*, 1967).

The most diverse assemblages are known from central regions of the Russian platform, where they include nearly 100 species. These regions are most central in the Boreal biogeographic belt, and likely were appropriate for both the boreal and subboreal ammonite taxa. The Tethyan-subboreal forms (those of *Macrocephalites, Choffatia, Peltoceras*, and other genera) were also able to migrate in this area, and thus contributed much to the general diversity of local ammonite assemblages. In passing from the north to south, changes in ammonite assemblages are so gradual that the boundaries between low-rank paleobiochores seem nebulous, and the general structure of the ammonite community is of the ecotone type. The most distinct boundary lies between the Boreal and Tethyan belts; nonetheless, it is still vague, and represents an ecotone, for instance, in the northern Caucasus. The early Callovian ammonites are represented here (Lominadze, 1982) by 58 species of the following higher taxa: Cardioceratidae (9 sp. of *Cadoceras* and 1 sp. of *Costacadoceras* genera); Kosmoceratidae (9 sp. of *Kepplerites* and 5 sp. of *Sigaloceras* genera); and Macrocephalitidae (26 sp. of *Macrocephalites* and 8 sp. of *Indocephalites* genera). Their chorologic systematics is as follows: boreal Cardioceratidae—17.5%, subboreal Kosmoceratidae—23.9%, Tethyan-subboreal *Macrocephalites*—44.7%, and Tethyan *Indocephalites*—13.9%. These data well illustrate the mingled chorologic composition of Callovian ammonites from the northern Caucasus. Accordingly, we may consider this region as an individual paleobiochore (ecotone), if it is not a unit of a larger biogeographic zone. Otherwise, being incorporated in a higher paleobiochore, the northern Caucasus should be regarded as a part of the Boreal belt.

Reviewer K.I. Kuznetsova

REFERENCES

Alekseev, S.N. and Repin, Yu.S., New Data on Callovian Deposits in the Malinovyi Ravine (Saratov District of the Volga Region), in *Yurskie otlozheniya Russkoi platformy* (Jurassic Deposits in the Russian Platform), Leningrad: Vses. Nauch.-Issled. Geol.-Razved. Inst., 1986, pp. 130–136.

Amanniyazov, K.N., *Biostratigrafiya, zoogeografiya i ammonity verkhnei yury Turkmenii* (Biostratigraphy, Zoogeography, and Upper Jurassic Ammonites of Turkmenistan), Ashkhabad: Akad. Nauk TajikSSR, 1971.

Amanniyazov, K.N., *Stratigrafiya i ammonity verkhneyurskikh otlozhenii Tuarkyra* (Stratigraphy and Ammonites from Upper Jurassic Deposits of the Tuarkyr Range), Ashkhabad: Akad. Nauk TajikSSR, 1962.

Bodylevskii, V.I., Boreal Province of the Jurassic Period, in *Voprosy paleobiogeografii i biostratigrafii* (Problems of Paleobiogeograpgy and Biostratigraphy), Moscow: Gosgeoltekhizdat, 1957, pp. 91–96.

Callomon, J.H., Dietl, G., and Niederhofer, H.-J., Die Ammonitenfaunen-Horizonte im Grenzbereich Bathonium/Callovium des Schwabischen Jura und deren Korrelation mit W-Frankreich and England, *Stutgarter Beitr. Naturk., Ser. B*, 1989, no. 148, pp. 1–13.

Callomon, J.H., Dietl, G., and Page, K.N., On the Ammonite Faunal Horizons and Standard Zonations of the Lower Callovian Stage in Europe, in *2nd Int. Symp. Jurassic Stratigraphy*, Lisboa, 1987, pp. 359–376.

Kamysheva-Elpat'evskaya, V.G., Nikolaeva, V.P., and Troitskaya, E.A., *Stratigrafiya yurskikh otlozhenii Saratovckogo pravoberezh'ya po ammonitam* (Ammonite Stratigraphy of Jurassic Deposits in Saratov District, Right Side of the Volga River), Leningrad: Gosgeoltekhizdat, 1959.

Keyserling, A., *Wissenschaftliche Beobachtung auf einer Reise in das Petschora-Land im Jahre 1843*, St. Petersburg, 1846.

Lominadze, T.A., *Kelloveiskie ammonity Kavkaza* (Callovian Ammonites from the Caucasus), Tbilisi: Metsniereba, 1982.

Meledina, S.V., *Ammonity i zonal'naya stratigrafiya kelloveya Sibiri* (Callovian Ammonites and Zonal Stratigraphy of Siberia), Moscow: Nauka, 1977.

Meledina, S.V., *Ammonity i zonal'naya stratigrafiya kelloveya Subboreal'nykh raionov SSSR* (Ammonites and Callovian Zonal Stratigraphy in Subboreal Regions of the USSR), Moscow: Nauka, 1987.

Nikitin, S.N., Der Jura der Umgegend von Elatma, *Mem. Soc. Natur.*, 1881, vol. 15, no. 1, pp. 1–51.

Nikitin, S.N., Der Jura der Umgegend von Elatma, *Mem. Soc. Natur.*, 1885, vol. 15, no. 2, pp. 43–66.

Paleogeografiya SSSR. Triasovyi, yurskii i melovoi periody (Paleogeography of the USSR. Triassic, Jurassic, Cretaceons), Mockow: Nedra, 1975, vol. 3.

Repin, Yu.S. and Rashwan, N.Kh., New Representatives of Kosmoceratidae (Ammonoidea) from the Callovian of Mangyshlak, *Ezheg. Vses. Paleontol. O-va*, Leningrad: Nauka, 1991, vol. 34, pp. 99–108.

Savel'ev, A.A., Paleontologically Substantiated Stratigraphy of Jurassic Deposits in Mangyshlak, *Tr. Vses. Nauch.-Issled. Geol.-Razved. Inst.*, 1963, vol. 218, pp. 209–235.

Savel'ev, A.A., Kalugin, A.K., Azbel', A.Ya., *et al.*, New Data on Stratigraphy of Jurassic Deposits in Mangyshlak, *Tr. Vses. Nauch.-Issled. Geol.-Razved. Inst.*, 1973, vol. 344, pp. 19–33.

Sazonov, N.T., New Data on Callovian, Oxfordian, and Kimmeridgian Ammonites, in *Fauna mezozoya evropeiskoi chasti SSSR i Srednei Azii* (Mesozoic Fauna from the European Part of the USSR and Central Asia), Moscow: Nedra, 1965, pp. 3–49.

Sazonov, N.T., *Yurskie otlozheniya tsentral'nykh oblastei Russkoi platformy* (Jurassic Deposits in Central Regions of the Russian Platform), Leningrad: Gostoptekhizdat, 1957.

Sokolova, E.I., Kosmoceratids from Upper Jurassic Deposits of Mangyshlak, Leningrad: Gostoptekhizdat, 1950, vol. 49, pp. 93–155.

Spath, L., The Invertebrate Faunas of the Bathonian–Callovian Deposits of Jameson Land (East Greenland), *Medd. Grnoland.*, 1932, vol. 87, no. 7, pp. 1–158.

Stehli, F.G., McAlester, A.L., and Helsey, C.E., Taxonomic Diversity of Recent Bivalvia and Some Implications for Geology, *Bull. Geol. Soc. Am.*, 1967, vol. 78, pp. 455–466.

Stratigrafiya yurskoi sistemy Severa SSSR (Stratigraphy of Jurassic System in the Northern USSR), Moscow: Nauka, 1976.

Zony yurskoi sistemy v SSSR (Zones of Jurassic System in the USSR), Leningrad: Nauka, 1982.

Stratigraphy and Geological Correlation, Vol. 4, No. 5, 1996, pp. 480–495. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 5, 1996, pp. 67–82.
Original Russian Text Copyright © 1996 by Beniamovskii, Gladenkov.
English Translation Copyright © 1996 by МАИК Наука/Interperiodica Publishing (Russia).

Paleogene Climatic Fluctuations and Biotic Migrations in the North Pacific

V. N. Beniamovskii and Yu. B. Gladenkov

Geological Institute of Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia

Received February 23, 1995

Abstract—Analysis of the Paleogene planktonic foraminifers from the sections of Kamchatka, Koryak Highland, the North Pacific, and Japan revealed several age levels of the occurrences of warm-water (subtropical) assemblages: late Danian, late Thanetian–early Ypresian, early Lutetian, early Bartonian, and early Priabonian. Appearance of these assemblages at high latitudes can be attributed to climatic warmings that led to their long-distance (up to 2000 or 2500 km) migrations in the northern direction. Some past climatic fluctuations can be correlated with eustatic sea-level oscillations. A high rate of migrations and relatively short duration of warming phases in comparison with cooling phases are recorded.

Keywords: *Paleogene, planktonic foraminifers, the northwest Pacific, climate, cooling, warming, migrations.*

INTRODUCTION

It is well known that stratigraphic succession of fossil assemblages allows us to date the enclosing deposits and understand the biotic evolution in the geological past. The paleobiotic changes in sections also provide us with other important information, particularly, on the character of climatic fluctuations and eustatic oscillations, extent of migrations, and so on. These paleogeographic and paleoclimatic data are of extreme importance for the detailed reconstruction of past environmental events, and for outlining their scenarios for future centuries. These data are also helpful for tectonics specialists in the interpretation of geological structures, for example, in the case when some structures with different fauna types are considered as exotic terrains. This article presents an attempt to reconstruct some paleogeographic phenomena, using the Cenozoic of the north Pacific as an example.

MATERIALS AND METHODS

The Paleogene and Neogene deposits of the north Pacific and framing structures are now under intense study. A number of articles and monographs dealing with new interpretations of both stratigraphic and paleogeographic problems have recently been published (Serova, 1964; Gladenkov *et al.*, 1991, 1992; Gladenkov and Shantser, 1993; Gladenkov, 1994; Shcherbinina, 1992; Beniamovskii and Fregatova, 1993; Basilyan *et al.*, 1993; Oreshkina, 1993; Barinov, 1994; Basov, 1993; Kaiho, 1991). Special emphasis was placed on the comparative analysis of data on different areas of this region, particularly on the low and high latitudes of the Pacific Ocean and the northeastern Asiatic margin. The study of Cenozoic sediments of the Sakhalin, Kamchatka, and the Koryak Highland, along with available data on Japan and the North Pacific, revealed changes in fossil assemblages not only in successive beds of the sections, i.e., in time, but also in the lateral direction for separate age levels. This provided grounds to understand the course and character of many paleogeographic events in both the North Pacific and the transitional zone from the ocean to the Asiatic continent.

A few years ago, a model of climatic fluctuations and related assemblage migrations was elaborated for different Neogene biogeographic provinces on the basis of the Neogene molluscan records in many sections from Japan in the south up to the Chuckchi Range in the north (Gladenkov, 1988; Gladenkov and Sinel'nikova, 1991). It was discovered first that in the Neogene time, there occurred several considerable warming events coincident with large sea transgressions in the transitional ocean–continent zone. Second, the periods of warming were characterized by long-distance northward prochoreses of warm-water (subtropical and south-boreal) biotas, whereas during the periods of cooling, northern faunas and floras migrated southward. These migrations were very significant in extent: for instance, during the first Miocene climatic optimum, the warm-water assemblages moved from Japan up to northern Kamchatka and the Koryak Highland, i.e., about 2000–2500 km. Certain biotic changes were also recorded in the lateral direction, e.g., the abundance decrease of warm-water biotic elements in the northern direction (and correspondingly cold-water elements toward the low latitudes). Also remarkable is the spatial convergence of warm- and cold-water biotic assemblages in the course of the migrations. Third, the time

range of the Neogene cooling events was several times as much as that of relatively short-term warming events.

Later, a similar analysis of the Paleogene biota from the same area (Gladenkov and Shantser, 1993) provided us with general information on climatic changes and biotic migrations. In particular, three climatic optima and three corresponding extensive migrations of warm-water assemblages from south to north were outlined from the data on molluscan and floral development. The latest data on the Paleogene plankton sheds new light on this problem.

In the Far East, many Paleocene–Eocene sections yielded representative assemblages of planktonic foraminifers, which permitted the application of detailed zonal stratigraphy (Beniamovskii *et al.*, 1992). An attempt to reconstruct some paleogeographic and biotic events on this basis is presented below. We analyzed the assemblages from all zonal units of the sections throughout the Northwest Pacific and framing structures (DSDP Sites 44, 463, 305, 577 in the Pacific Ocean and natural exposures in Japan, Kamchatka, and the Koryak Highland) (Krasheninnikov, 1969, 1981, 1982; Krasheninnikov *et al.*, 1988; Serova, 1969, 1978; Serova *et al.*, 1980; Alabusheva, 1989; Beniamovskii *et al.*, 1992; Fisher *et al.*, 1971; Kaiho, 1983; Kaiho and Saito, 1986; Corfield, 1987).

Figure 1 shows the location of reference Paleogene sections of the region, which are confined both to low and high latitudes. A stratigraphic range of each section containing planktonic foraminifers is also indicated.

Changes in the Paleogene assemblages of planktonic foraminifers in the Northwest Pacific sections are attributable to both their evolution, and to different abiotic events, the principal of which were climatic fluctuations, sea transgressions, and regressions.

Relative to the sea water temperature, the North Pacific Paleogene planktonic foraminifers can be classified into three groups. The first group consists of tropical thermophilic forms that inhabited mainly the tropical areas. They seldomly migrated into the subtropical zone, and are absent in the Northwest Pacific sections to the north of 40°N. The second group contains relatively warm-water subtropical species (*Eoglobigerina, Morozovella, Acarinina, and Globigerinatheka* representatives) that migrated during the periods of warming into the high latitudes up to 60°N. Finally, the third group of species (most of *Subbotina, Pseudohastigerina, Globorotaloides, Catapsydrax*) inhabited the high-latitude basins. Although their representatives were also found in the warm-water area, they can serve as general indicators of high-latitude environments (Premoli Silva and Boersma, 1989).

For comparison, the recent North Pacific biota comprises three large groups of planktonic foraminifers (Belyaeva, 1969). To the north of 40°N, fauna is of the boreal-subarctic type dominated by representatives of the Globigerinidae family. To the south, between 20 and 40°N, there is a subtropical group which shows an increased importance of Globorotaliidae forms (up to 50% of the assemblage). Finally, the third biocoenotic group is tropical, and here the content of Globorotaliidae forms exceeds 50%, frequently reaching 100%. It is worth noting that boreal *Globigerina* and *Globoquadrina* mark their southerly distribution up to the equatorial area, where they are scarce. The northern limit of the Globorotaliidae distribution is recorded at 40°N, and coincides with that of the oceanic warm-water area.

Some peculiarities of the paleobiotic changes in the studied sections should be noted. The reference Paleogene section of Kamchatka and the Koryak Highland is located in the Il'pinskii Peninsula (Volobueva *et al.*, 1994). The Paleocene-Eocene deposits of the section are uniformly rich in planktonic foraminifers (Beniamovskii *et al.*, 1992). The distribution of their characteristic assemblages is shown in Fig. 2. There are several levels with warm-water assemblages (from the base upward).

Warm-water *Acarinina* (*A. soldadoensis, A.* cf. *acarinata*) and *Morozovella* (*M. aequa*) were found in the upper part of the Yuzhno-Il'pinskii Formation (upper Thanetian). These forms are accompanied by some cosmopolitan species, which are widespread in the temperate climatic zone, and also present in the warm-water area: *Subbotina nana* (Plate I, figs. *1–3*), *S. velascoensis* (Plate I, figs. *4* and *5*), *S. bacuana* (Plate I, figs. *12–14*), *S. triloculinoides*, and *S.* aff. *linaperta*.

The next warm-water tropical-subtropical assemblage with *Morozovella subbotinae* (Plate II, figs. *16* and *17*), *M. reissi* (Plate II, figs. *18* and *19*), *M. wilcoxensis* (Plate II, figs. *14* and *15*), and *Acarinina whitei* is recorded in the lower Kylan Subformation (lower Ypresian). Relatively thermophilic *Subbotina boweri* (a small-size variety) occurs in the uppermost part of the formation (early Lutetian).

One more warm-water assemblage including *Subbotina boweri* (Plate II, figs. *24–26*), *S. frontosa* (Plate II, figs. *2* and *3*), and *Globigerinatheka* cf. *index* (Plate II, fig. *1*) was found in the overlying upper Kilakirnun Subformation (lower Bartonian). Finally, the tropical species *Globigerinatheka* cf. *tropicalis* (Plate I, fig. *22*) appears at the top of the Kilakirnun Formation (lower Priabonian).

In general, the distribution of planktonic foraminifers throughout the section shows the alternation of warm-water forms (*Morozovella*, some *Subbotina*, *Acarinina*, and *Globigerinatheka*) with assemblages lacking the subtropical elements and consisting of widespread forms (*Subbotina, Pseudohastigerina*, and *Globorotaloides*) only. The warm-water forms appeared in the following age intervals: late Danian, late Thanetian–early Ypresian, early Lutetian, early Bartonian, and early Priabonian. For comparison, we present below some data on the adjacent regions.

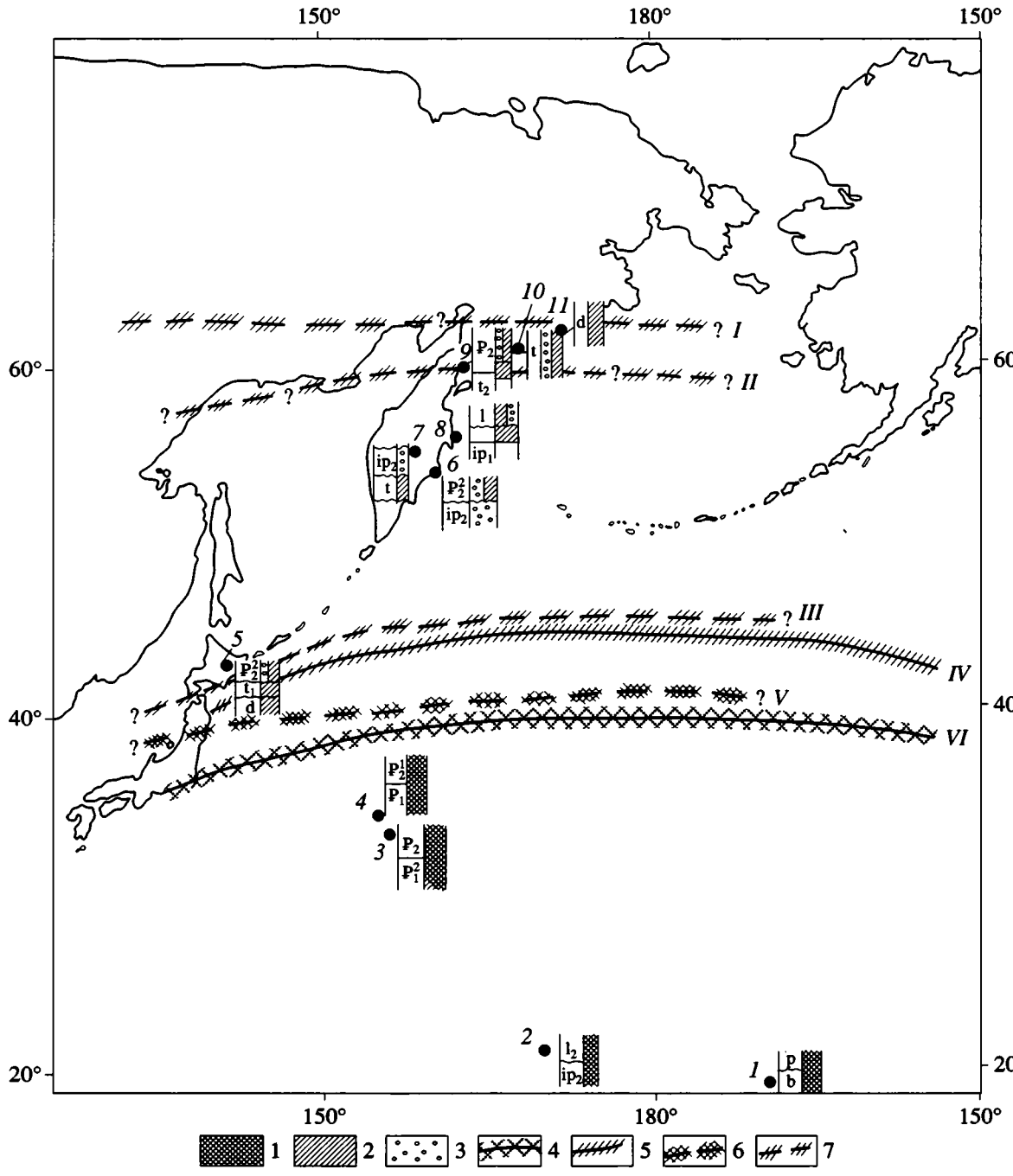


Fig. 1. Paleogene reference sections and climatic zones in the Northwest Pacific.

Reference sections numbered in the figure: the Mid-Pacific Mountains: (*1*) Hole 44, (*2*) Hole 463; the Schatsky Rise: (*3*) Hole 305, (*4*) Hole 47; (*5*) Hokkaido; (*6*) Kronotskii Peninsula; (*7*) Valaginskii Range; (*8*) Kamchatskii Cape; (*9*) Il'pinskii Peninsula; (*10*) Pylgavayam River basin; (*11*) Khatyrka depression.

Types of planktonic foraminifer assemblages: (1) warm-water, tropical; (2) warm-water, subtropical; (3) moderately warm-water. Northern boundaries of the climatic zones for Recent time: (4) tropical, (5) subtropical; and for Paleocene and Eocene: (6) tropical, (7) subtropical.

Northern boundaries of the climatic zones for different time intervals in subtropical zone: (*I*) Paleocene and initial early Eocene (warming); (*II*) middle Eocene (warming); (*III*) Eocene (cooling); (*IV*) Recent (Galerkin *et al.*, 1982); in tropical zone: (*V*) Paleocene and Eocene; (*VI*) Recent (Galerkin *et al.*, 1982).

Symbols: P_1 *Paleocene*, (d) Danian, (P_1^2) upper Paleocene, (t) Thanetian, (P_2) Eocene, (P_2^1) lower Eocene, (ip_2) upper Ypresian, (P_2^2) middle Eocene, (l) Lutetian, (b) Bartonian, (p) Priabonian.

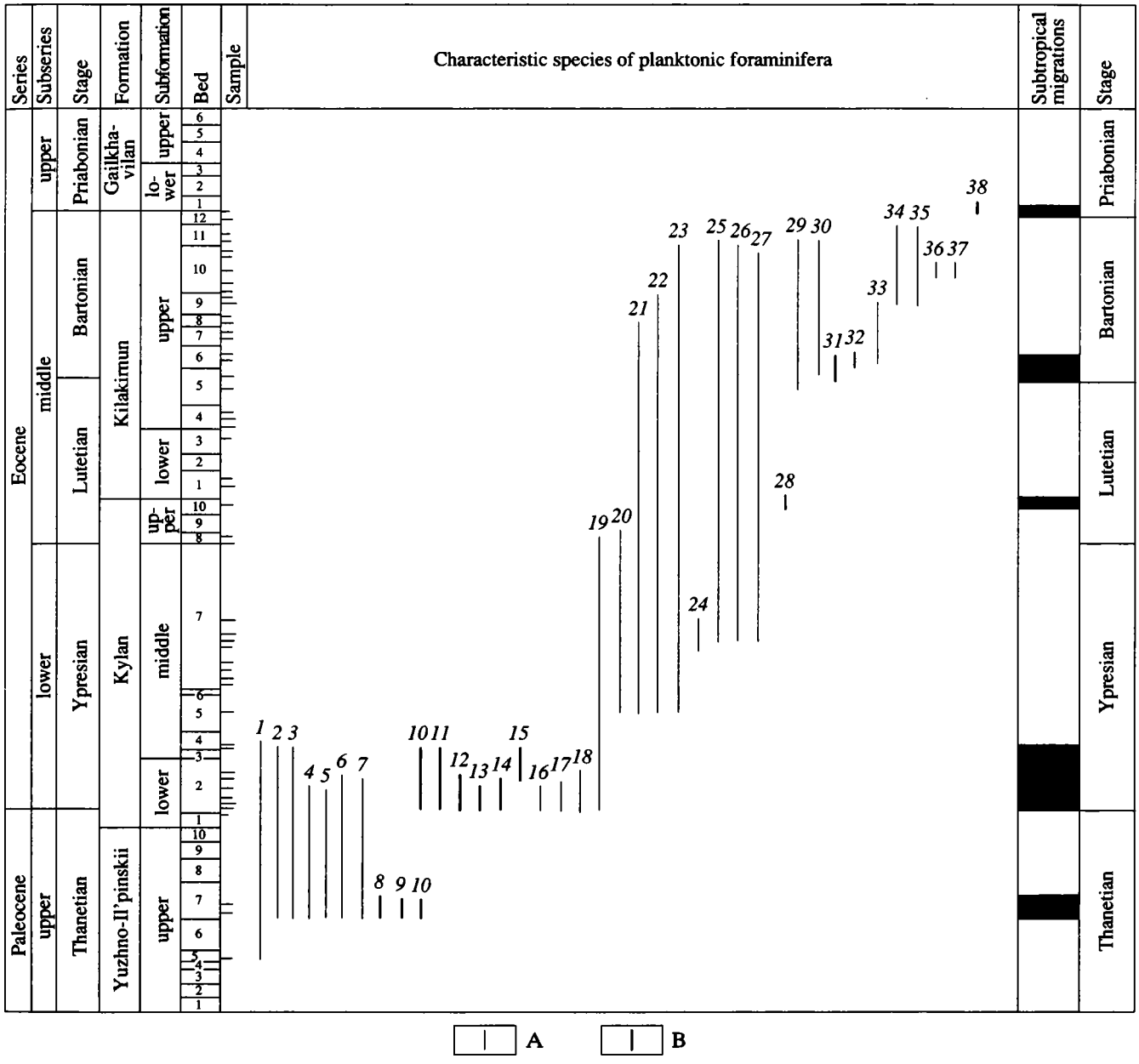


Fig. 2. Distribution of characteristic warm-water and cosmopolitan species of planktonic foraminifers in the Paleogene section of the Il'pinskii Peninsula (eastern Kamchatka, Paleocene–Eocene).

(*1*) *Subbotina nana* (Khalilov), (*2*) *S. velascoensis* (Cushman), (*3*) *S. bacuana* (Khalilov), (*4*) *S. triloculinoides* (Plummer), (*5*) *S. pileata* (Khalilov), (*6*) *S. angipora* (Stache), (*7*) *S.* aff. *linaperta* (Finlay), (*8*) *Acarinina soldadoensis* (Bronnimann), (*9*) *A.* cf. *acarinata* Subbotina, (*10*) *Morozovella aequa* (Cushman et Renz), (*11*) *M. wilcoxensis* (Cushman), (*12*) *M. subbotinae* (Morozova), (*13*) *Acarinina whitei* (Weiss), (*14*) *Morozovella convexa* (Subbotina), (*15*) *M. reissi* (Loeblich et Tappan), (*16*) *Subbotina compressaeformis* (Khalilov), (*17*) *S. contorta* (Schutzkaja), (*18*) *S. aequiensis* (Loeblich et Tappan), (*19*) *S. patagonica* (Todd et Kniker), (*20*) *Globorotaloides* ex gr. *suteri* Bolli, (*21*) *Subbotina pseudoeocaena pseudoeocaena* (Subbotina), (*22*) *S. inaequispira* (Subbotina), (*23*) *Pseudohastigerina wilcoxensis* (Cushman et Ponton), (*24*) *P. micra* (Cole), (*25*) *Subbotina* ex gr. *turgida* (Finlay), (*26*) *S. linaperta* (Finlay), (*27*) *S. posttriloculinoides* (Khalilov), (*28*) *S. eocaenica irregularis* (Subbotina), (*29*) *S. boweri* (Bolli), small-size form, (*30*) *S.* ex gr. *inaequispira* (Subbotina), (*31*) *Globorotaloides suteri* (Finlay), (*32*) *Subbotina boweri* (Bolli)–*S. frontosa* (Subbotina), (*33*) *Globigerinatheka* cf. *index* (Finlay), (*34*) *Subbotina pseudoeocaena compacta* (Subbotina), (*35*) *S. incretacea* (Khalilov), (*36*) *S. praebulloides* (Blow), (*37*) *Acarinina* cf. *rugosoaculeata* (Subbotina), (*38*) *Catapsydrax dissimilis* (Blow et Banner).

(A) Cosmopolitan species, (B) warm-water (tropical-subtropical) species.

Excellent sequences containing abundant and diverse assemblages of planktonic foraminifers were recovered by DSDP Holes 47, 305, 577 and others in the Schatsky Rise, the Northwest Pacific. In the continuous succession of the Paleocene–basal middle Eocene sediments, the standard subglobal zonation of planktonic foraminifers was established. The assemblages are represented by abundant and diverse warm-water species of *Eoglobigerina*, some *Subbotina, Acarinina, Planorotalites*, and *Morozovella*, which are associated with broadly distributed *Subbotina* and *Pseudohastigerina*. Their descriptions were given in well-known publications (Krasheninnikov, 1981, 1982; Corfield, 1987).

The most complete sequences of the middle and upper Eocene were recovered by the holes located to the south, in the Mid-Pacific Mountains region (Holes 44, 463, and others). The assemblages of warm-water *Subbotina, Morozovella, Globigerinatheka, Orbulinoides, Truncorotaloides*, and *Cribrohantkenina*, together with species of middle latitudes, such as *Pseudohasterigerina, Globorotaloides*, and *Subbotina*, were reported from these sediments (Krasheninnikov, 1982).

Also of interest is the data on Hokkaido, Japan, where the studied section exposes the deposits transitional from the Cretaceous to Paleogene (Kaiho and Saito, 1986). The upper Maastrichtian deposits are overlain by the Danian beds containing foraminifers that are characteristic of the lowermost Danian *Eoglobigerina eugubina* and *Subbotina praebulloides* zones. The Katsuhira Formation of eastern Hokkaido that yielded *Globoconusa daubjergensis, Planorotalites compressa*, and *Subbotina pseudobulloides* corresponds to the next *Globoconusa daubjergensis* Zone of the Danian. The Thanetian species *Planorotalites pseudomenardii* was found in the overlying Chippomanai Formation (Krasheninnikov, 1969). According to Boersma and Premoli Silva (Premoli Silva and Boersma, 1989; Boersma and Premoli Silva, 1991), Danian *Subbotina praebulloides* and late Paleocene *Planorotalites* are inhabitants of the middle latitudes. Therefore, the warm-water character of the assemblages from both formations may be suggested. The third period of warming was reflected in the occurrence of relatively warm-water middle Eocene *Subbotina boweri* and *S. frontosa* in the upper part of the Kawaruppu Formation (Kaiho, 1983).

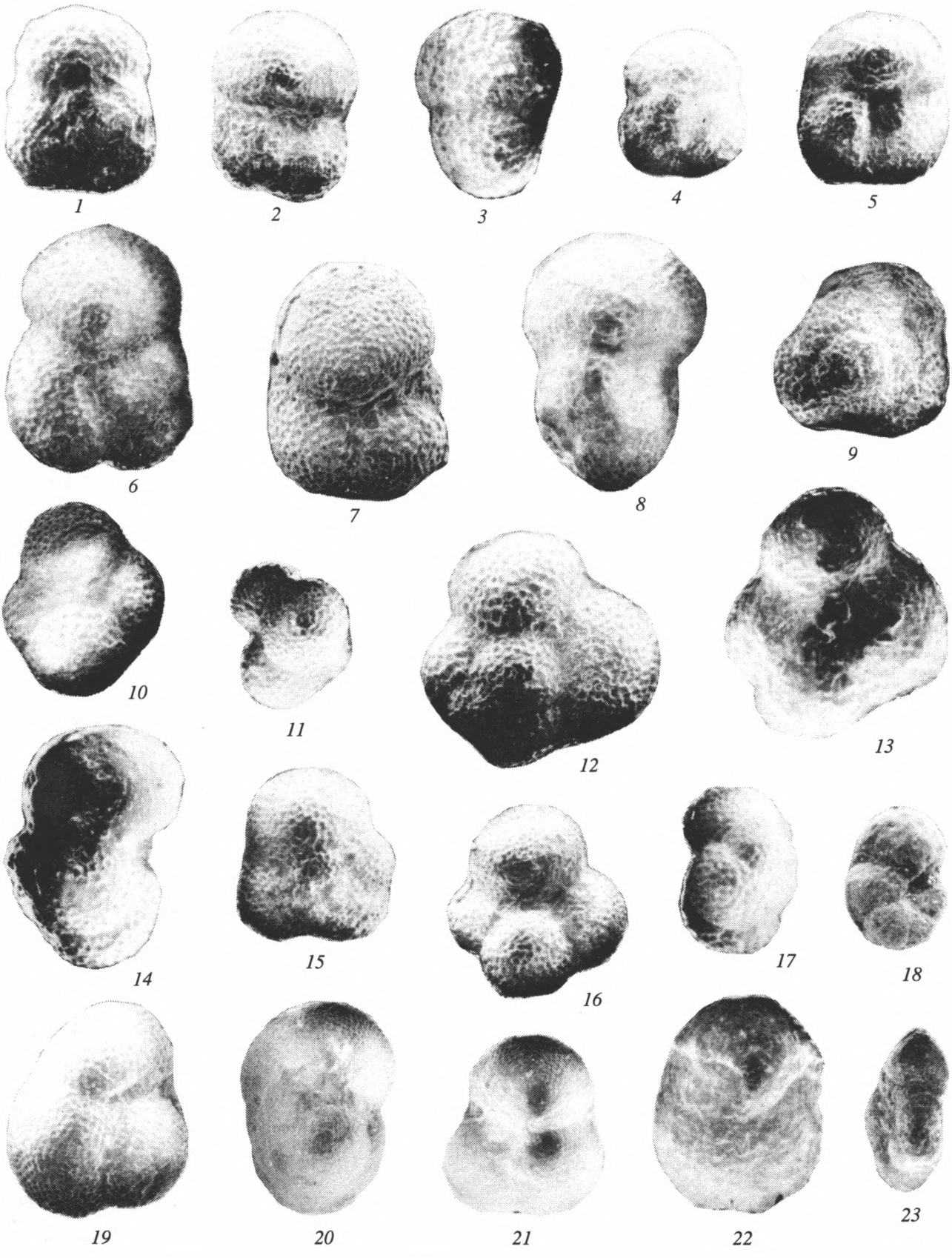
In recent years, new material became available on different sections of Kamchatka. Foraminifers were found in the reference Il'pinskii section of northeastern Kamchatka and in the southern areas—the Valaginskii Range and the Kronotskii and Kamchatskii Mys peninsulas (Beniamovskii *et al.*, 1992; Bakhteev *et al.*, 1994). The Thanetian deposits of the Vetlovka Formation in the Valaginskii Range yielded warm-water *Acarinina subsphaerica, Planorotalites ehrenbergi, P. pseudomenardii, Morozovella* sp., and *M. aequa*.

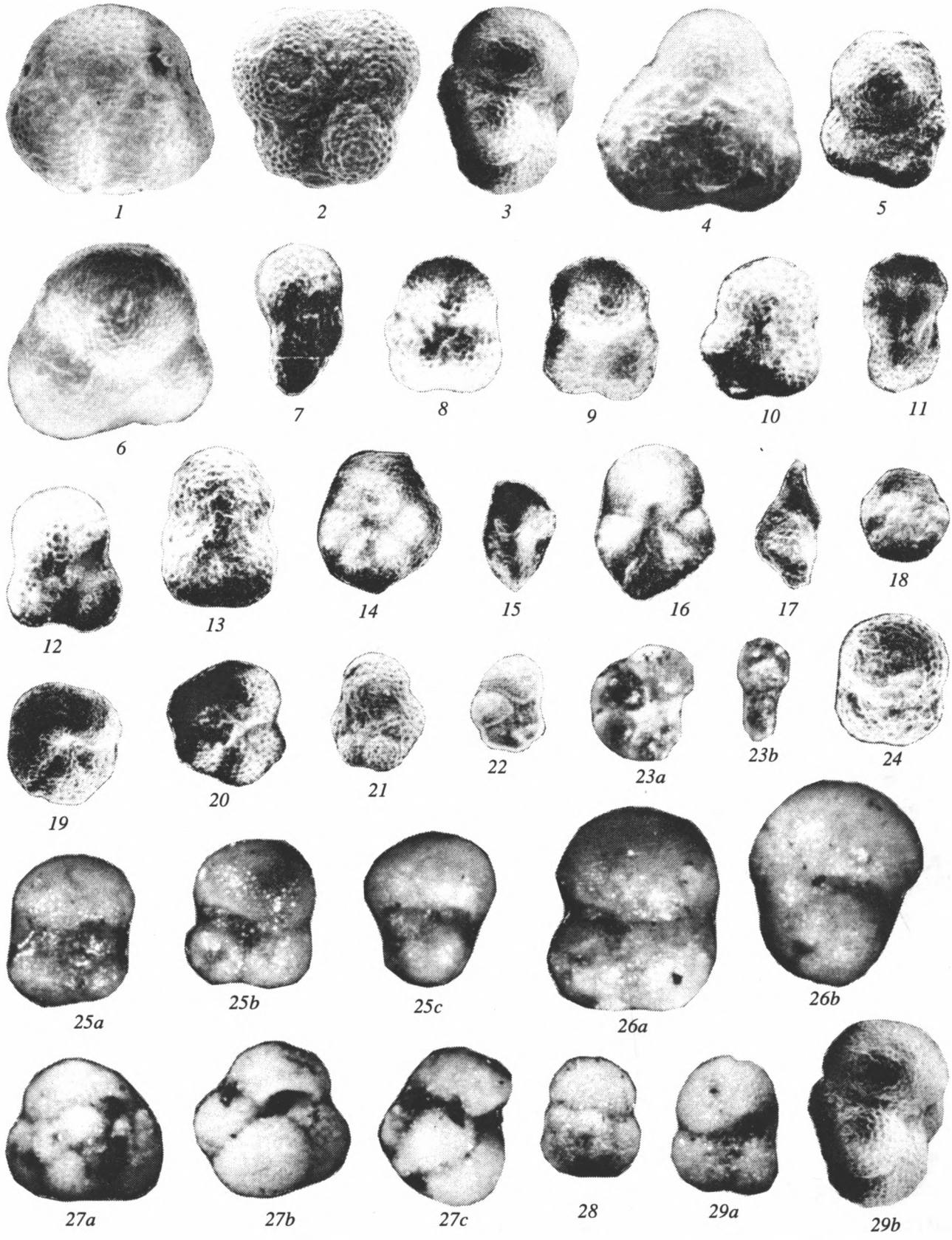
Remarkable Paleocene plankton was also found to the north of the Il'pinskii Peninsula, in the Koryak Highland. An assemblage of late Danian planktonic foraminifers, including *Euglobigerina* cf. *fringa, Subbotina pseudobulloides, S. trinidadensis*, and *S. triloculinoides*, was recorded in the Paleogene section recovered by the Khatyrka Well (Alabusheva, 1989). Boersma and Premoli-Silva (1991) cited *E. fringa* and *S. trinidadensis* as indicators of low-latitude plankton and *S. pseudobulloides* as a form typical of middle latitudes. In the Pylgavayam River basin and the Goven Peninsula, there occur the Thanetian species of a wide geographic distribution (*Subbotina nana, S. velascoensis, S. triangularis, S. triloculnoides*, and *S. posttriloculinoides*) together with warm-water *Acarinina acarinata, A. primitiva*, and *Planorotalites elongata* (Serova *et al.*, 1980).

CLIMATIC FLUCTUATIONS AND BIOTIC MIGRATIONS

The consecutive analysis of the Paleogene foraminiferal assemblages from the southern sections to northern ones revealed two peculiarities. First, relatively warm-water (subtropical) forms were found at several levels in the high-latitude sections (eastern Kamchatka and the Koryak Highland). These are five levels: upper

Plate I. (*1–3*) *Subbotina nana* (Khalilov). The Kylan Formation: (*1*) sp. no. 402/5b (1), spiral side; (*2*) sp. no. 408/8f (1), umbilical side; (*3*) sp. no. 402/6a (1), lateral side.
(*4, 5*) *Subbotina velascoensis* (Cushman). The Kylan Formation: (*4*) sp. no. 402/6b (3), spiral side; (*5*) sp. no. 402/6b (4), umbilical side.
(*6, 7, 8*) *Subbotina compressaeformis* (Khalilov). The Kylan Formation: (*6*) sp. no. 402/6b (5), spiral side; (*7*) 9p. no. 23/6c (2), umbilical side; (*8*) sp. no. 23/6a (1), lateral side.
(*9, 10, 11*) *Subbotina aequiensis* (Loeblich and Tappan). The Kylan Formation: (*9*) sp. no. 408/8f (2), lateral side; (*10*) sp. no. 24/10 (2), umbilical side; (*11*) sp. no. 24/10a (3), spiral side.
(*12, 13, 14*) *Subbotina bacuana* (Khalilov). The Kylan Formation: (*12*) sp. no. 402/6b (2), spiral side; (*13*) sp. no. 402/4b (1), umbilical side; (*14*) sp. no. 402/6b (1), lateral side.
(*15, 16, 17*) *Subbotina pseudoeocena pseudoeocena* (Subbotina). The Kylan Formation: (*15*) sp. no. 408/8d (2), spiral side; (*16*) sp. no. 401/8d (3), umbilical side; (*17*) sp. no. 401/8d (4), lateral side.
(*18, 23*) *Pseudohastigerina micra* (Cole). The Kozlovskaya Formation (the Kronotskii Peninsula): (*18*) sp. no. 438/2 (1), lateral side; the Kilakirnun formation: (*23*) ap. no. 400/3d (4), view from aperture.
(*19, 20, 21*) *Subbotina frontosa* (Subbotina). The Kilakirnun Formation: (*19*) 8p. no. 400/9b (2), umbilical side; (*20*) gp. no. 400/8b (3), lateral side; (*21*) sp. no. 400/2b (1), umbilical side.
(*22*) *Globigerinatheka* cf. *tropicalis* (Blow and Banner). The Kilakirnun Formation: (*22*) sp. no. 400/1a (1), lateral side.
All images in the plates are given with ×100 magnification.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23a
23b
24
25a
25b
25c
26a
26b
27a
27b
27c
28
29a
29b

Danian, Thanetian–lower Ypresian, lower Lutetian, upper Lutetian, lower Bartonian, and lower Priabonian.

Second, the mapped distribution of the above-listed Paleogene warm-water subtropical assemblages shows several (at least four or five) migrations for a distance of 2000–2500 km in the northern direction. The displacements of the northern boundary of the subtropical zone for 18°–20° to the north were caused by significant warmings (Fig. 1).

The extent of the boundary displacement seems to be different. For instance, in the early Paleocene the boundary was located in the Koryak Highland region; in late Ypresian and middle Lutetian it moved down for 18°–20° from high latitudes to Hokkaido; and during the late Lutetian–early Bartonian and early Proabonian optima it only reached northern Kamchatka, i.e., was displaced for several degrees to the south relative to the early Paleocene position.

Thus, it may be suggested that the migrations (peculiar injections of subtropical biota in the northern direction), different in extent, took place in the north Pacific during the Paleogene. To illustrate the spatial extent of the migrations at certain periods of geological time, they are shown in Fig. 3 as peculiar wedges oriented from the south to the north. However, it should not be supposed that the warm-water assemblages remained unchanged in different distribution areas: their taxonomic and quantitative compositions varied with latitude. In southern latitudes, the assemblages are rich in warm-water forms, whereas in northern latitudes, these forms are considerably less diverse.

The upper Danian sediments of the Schatsky Rise yielded a diverse assemblage, including warm-water representatives of genera *Chiloguembelina, Eoglobigerina*, and *Subbotina*. In the Koryak Highland (2000–2500 km to the north), the main components of the assemblage are represented by rare or single species of the low-latitude planktonic *Eoglobigerina* cf. *fringa, Subbotina pseudobulloides*, and *S. trinidadensis*.

The Thanetian migration shows the following changes in the assemblages from the south to the north. In the south, the Thanetian zones (Hole 47, the Schatsky Rise) contain numerous warm-water species of *Morozovella* (15 species), *Planorotalites* (three species), *Acarinina* (seven species) and *Subbotina* (two species), as well as five species of *Subbotina*, which have broad distribution. The warm-water forms comprise about 84% of the assemblage. In the north (at the latitude of the Il'pinskii Peninsula), the warm-water wedge became noticeably narrower. The warm-water forms constitute 29%, and cosmopolitan *Subbotina*, comprises the remaining 71%. Further to the north (the Pylgavayam River basin), *Morozovella* disappears and only the warm-water *A. acarinina acarinata* remains.

In the north, the early Ypresian warm-water *Morozovella subbotinae* (Plate II, Figs. *16* and *17*) and *M. reissi* (Plate II, Figs. *18* and *19*) have smaller tests, thinner walls, and less coarse ornamentation. These morphological changes were reported for the Paleogene warm-water planktonic forms from high latitudes of the Pacific (Krasheninnikov *et al.*, 1988) and Atlantic (Premoli Silva and Boersma, 1989) oceans.

Plate II. (*1*) *Globigerinatheka* cf. *index* (Finlay). The Kilakirnun Formation:
(*1*) sp. no. 400/8a (5), lateral side.
(*2, 3*) *Subbotina eocaena* (Guembel). The Kylan Formation: (*2*) ap. no. 401/8d (6), umbilical side; (*3*) sp. no. 400/20a (2), lateral side.
(*4, 6*) *Subbotina posttriloculinoides* (Khalilov). The Kylan Formation: (*4*) ap. no. 401/3b (1), spiral side; the Kilakirnun Formation: (*6*) gp. no. 400/8c (1), umbilical side.
(*5, 7*) *Subbotina inaequispira* (Subbotina). The Kylan Formation: (*5*) ap. no. 23/3b (2), umbilical side; (*7*) ap. no. 400/3b (1), lateral side.
(*8, 9, 10, 11*) *Subbotina linaperta* (Finlay). The Kylan Formation: (*8*) sp. no. 401/6b (1), spiral side; (*9*) ap. no. 500/3c, umbilical side; the Kilakirnun Formation: (*10*) ap. no. 400/9b (1), umbilical side; (*11*) sp. no. 400/9b (2), lateral side.
(*12, 13*) *Subbotina eocaenica irregularis* (Subbotina). The Kylan Formation: (*12*) sp. no. 401/8d (4), spiral side; (*13*) sp. no. 401/8d (5), umbilical side.
(*14, 15*) *Morozovella wilcoxensis* (Cushman and Ponton). The Kylan Formation: (*14*) sp. no. 402/6a (2), spiral side; (*15*) sp. no. 402/4b (2), lateral side.
(*16, 17*) *Morozovella subbotinae* (Morozova). The Kylan Formation: (*16*) sp. no. 402/5b (5), umbilical side; (*17*) sp. no. 408/8f (1), lateral side.
(*18, 19*) *Morosovella reissi* (Loeblich and Tappan). The Kylan Formation: (*18*) sp. no. 402/6b (6), spiral side; (*19*) sp. no. 408/8f (2), umbilical side.
(*20*) *Globorotaloides* ex gr. *suteri* Bolli. The Kilakirnun Formation: (*20*) sp. no. 400/10a (2), spiral side.
(*21, 22, 23a, 23b*) *Pseudohastigerina wilcoxensis* (Cushman and Ponton), The Kylan and Kilakirnun formations: (*21*) sp. no. 401/8c (1), lateral side; (*22*) sp. no. 401/8c (8), lateral side; (*23a*) 8p. no. 401/8c (3), lateral side; (*23b*) sp. no. 401/8c (3), aperture view.
(*24, 25a, 25b, 25c, 26a, 26b*) *Subbotina boweri* (Bolli). The Kilakirnun Formation: (*24*) sp. no. 400/8b (20), spiral side; (*25a*) sp. no. 400/8b (7), spiral side; (*25b*) sp. no. 400/8b (7), umbilical side; (*25c*) sp. no. 400/8b (7), lateral side; (*26a*) sp. no. 400/8b (5), spiral side; (*26b*) sp. no. 400/8b (6), lateral side.
(*27a, 27b, 27c*) *Catapsydrax dissimilis* Bolli. The Kilakirnun formation: (*27a*) sp. no. 400/3d (7), spiral side; (*27b*) sp. no. 400/3d (7), umbilical side; (*27c*) sp. no. 400/3d (7), lateral side.
(*28, 29a, 29b*) *Subbotina praebulloides* (Bolli). The Kilakirnun formation: (*28*) sp. no. 400/3d (8), spiral side; (*29a*) sp. no. 400/3d (9), umbilical side; (*29b*) sp. no. 400/3d (9), lateral side.

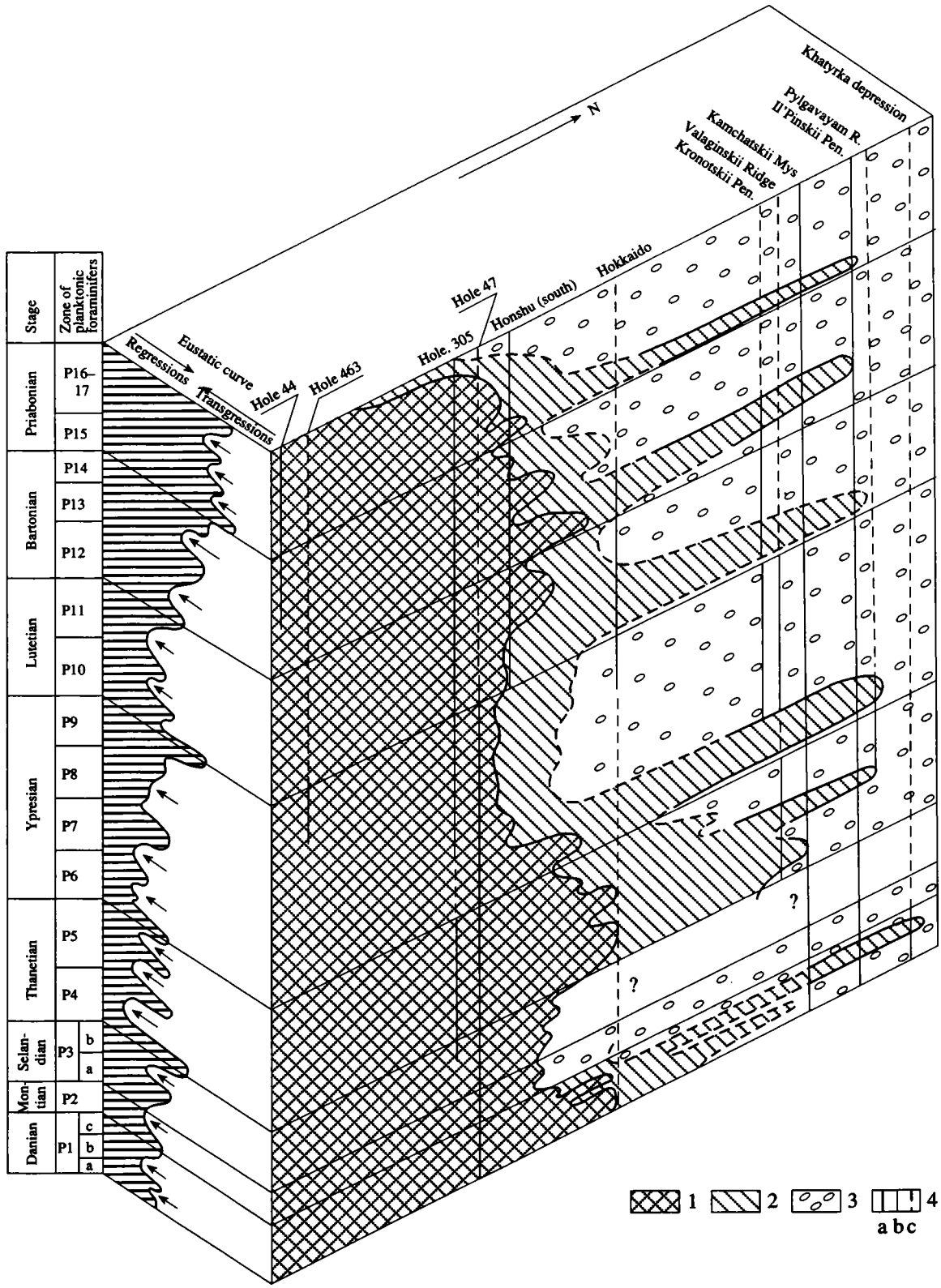


Fig. 3. Migrations of the Paleogene assemblages of planktonic foraminifera in the Northwest Pacific.
Assemblage types: (1) tropical, (2) subtropical, (3) subtropical, moderately warm-water; (4) location and completeness of the sections: (a) reliably zoned deposits, (b) deposits lacking zonation, (c) deposits are absent.

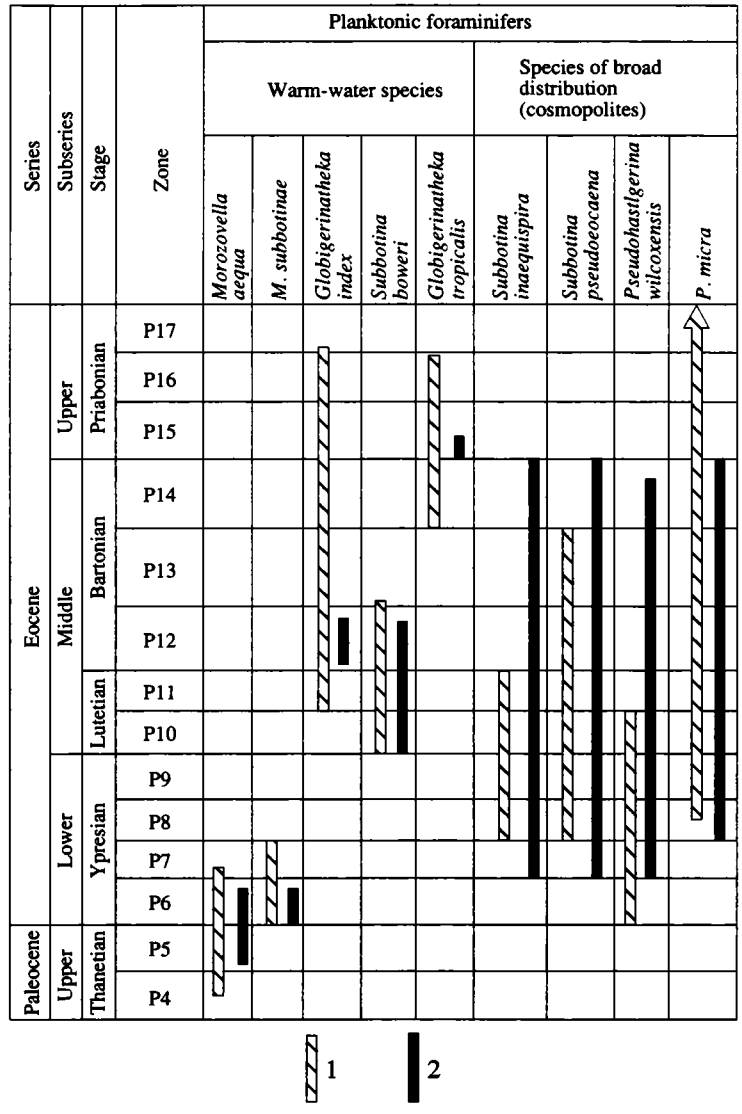


Fig. 4. Stratigraphic ranges of planktonic foraminifers in the North Pacific paleoclimatic zones.
(1) in the tropical–subtropical zone (Krasheninnikov *et al.*, 1988); (2) in the subtropical-temperate zone (Beniamovskii *et al.*, 1992; Volobueva *et al.*, 1994).

The early Lutetian migration to the north is reflected in the appearance of a single warm-water form *Subbotina boweri*. The late Lutetian–early Bartonian migration is marked by three species: *Subbotina frontosa, S. boweri* (a large-size form), and *Globigerinatheka* cf. *index*, and the early Priabonian one resulted in appearance of a single species *G.* cf. *tropicalis*.

The foraminifer distribution through the section shows that the warm-water wedges are separated by the intervals dominated by cosmopolitan forms. The assemblages of the middle-upper Ypresian and Lutetian intervals are uniform in composition: *Subbotina inaequispira* (Plate II, Figs. *5* and *7*), *S. pseudoeocaena* (Plate I, Figs. *15* and *16*), *S. posttriloculinoides* (Plate II, Figs. *4* and *6*), *S. eocaenica irregularis* (Plate II, Figs. *12* and *13*), *S. patagonica, S. linaperta* (Plate II, Figs. *8–11*), *Pseudohastigerina wilcoxensis* (Plate II, Figs. *21–23*), *P. micra* (Plate I, Figs. *18* and *23*), and *Globorotaloides* ex gr. *suteri* (Plate II, Fig. *20*). In addition, in the middle-upper Bartonian interval there appeared some other species: *Subbotina incretacea, S. praebulloides* (Plate II, Figs. *28* and *29*), *A.* cf. *rugosoaculeata, Catapsydrax dissimilis* (Plate II, Fig. *27*), and *Globorotaloides suteri*.

It should be noted that some representatives of *Subbotina, Pseudohastigerina, Globorotaloides* and *Catapsydrax* are prevalent in the high-latitude Atlantic provinces (Premoli Silva and Boersma, 1989; Boersma and Premoli Silva, 1991). It is natural that the definition of the stratigraphic position of the beds with warm-water

Correlation of the Paleocene–Eocene zonations based on planktonic foraminifers for different regions of the North Pacific

Series	Subseries	Stage	Tropical-south subtropical area	The Northwest Pacific (Far East region)
Eocene	upper	Priabonian	*T. centralis–G. gortanii*	No data
			G. cocoaensis	
			G. semiinvoluta	*Globigerinatheka tropicalis*
	middle	Bartonian	*T. rohri*	*Subbotina praebulloides*
			O. beckmanni	
			M. lehneri	*Globigerinatheka index*
		Lutetian	*G. kugleri*	*Subbotina boweri*
			H. aragonensis	
	lower	Ypresian	*M. palmerae*	*Pseudohastigerina wilcoxensis*
			M. aragonensis	
			M. formosa	
			M. subbotinae	*Morozovella wilcoxensis*
Paleocene	upper	Thanetian	*M. velascoensis*	*Morozovella aequa*
			P. pseudomenardii	*Planoratalites pseudomenardii*
		Selandian	*M. pusilla*	No data
			M. angulata	
	lower	Danian	*A. uncinata*	
			S. trinidadensis	*Subbotina trinidadensis–S. pseudobulloides*
			S. preudobulloides	
			E. eugubina	

assemblages should be based on their accurate assignment to the zonal scale. However, as already mentioned, stratigraphic ranges of warm-water species at the low latitudes may not coincide with those at the high latitudes (Fig. 4). Meanwhile, the succession of the assemblages and the evolution of planktonic foraminifers are generally similar in both regions. This served as a basis for defining the stratigraphic ranges of the early Lutetian, early Bartonian and early Priabonian species in the northern latitudes. These inferences are supported by the simultaneous appearance of some warm-water *Globigerinatheka*, and *Subbotina* in the middle–high latitude sections of the north Atlantic and East European paleobiogeographic areas.

The data on planktonic foraminifers is in good agreement with that on the nannoplankton of the Il'pinskii Peninsula (Gladenkov *et al.*, 1988), where four levels of nannoplankton occurrences were recorded. The first, oldest assemblage (at the level of the *Subbotina nana* Zone) is dated as Thanetian; the second assemblage (the *Morozovella wilcoxensis* Zone), as early Ypresian; the third assemblage (the *Pseudohastigerina wilcoxensis* Zone), as middle–late Ypresian; and the fourth assemblage (the *Subbotina praebulloides* Zone), as Bartonian.

To conclude this section, we indicate another important fact related to certain differences in the biotic assemblages from different Pacific latitudes. The fact that taxomonic compositions and appearance levels of characteristic and zonal planktonic species are not coincident in the low–middle and middle–high latitude zones of the Pacific explains available different Paleogene zonations for the North Pacific. The table presents a correlation between the Paleogene zonations based on planktonic foraminifers for two areas of the Northwest Pacific: tropical–subtropical and northern subtropical (the transitional zone from ocean to continent). The table is based on the plankton distribution in the high-latitude areas of the Pacific Ocean and the Bering Sea sector of the Northwest Pacific (Krasheninnikov *et al.*, 1988; Beniamovskii *et al.*, 1992; Volobueva *et al.*, 1994).

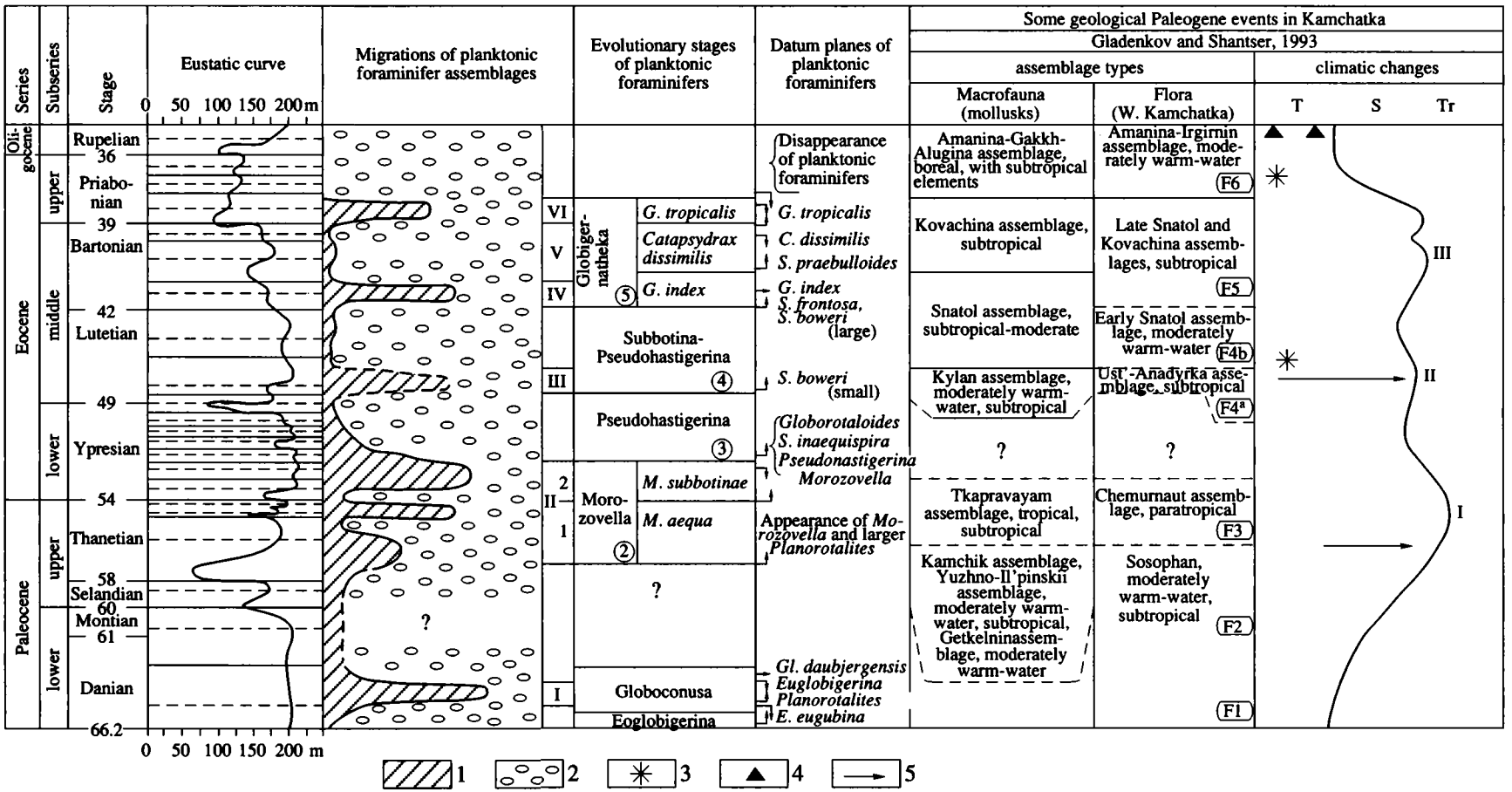


Fig. 5. Abiotic and biotic Paleogene events in the Northwest Pacific: time scale, eustatic curve, and stage subdivisions after Haq *et al.* (1987) with modifications after Naidin and Beniamovskii (1989, 1994).

Types of planktonic foraminifer assemblages: (1) subtropical, (2) moderately warm-water; (3) glendonites; (4) mass diatom appearance; (5) molluscan migrations; climate: (T) temperate, (S) subtropical, (Tr) tropical; (I–III) climatic optima.

CLIMATIC CHANGES, SEA TRANSGRESSIONS, AND EUSTATIC OSCILLATIONS

The defined Paleogene climatic phases of relative warming and cooling in the Northwest Pacific are generally coincident with those in other Pacific areas (Kennet and Stott, 1991). In some cases, water temperature determinations were provided by the isotopic method. For instance, as far back as the 1970s, Douglas and Savin (1975) reported on the oxygen isotope composition in tests of planktonic foraminifers and paleotemperatures determined for the North Pacific Paleogene in the Schatsky Rise (Holes 47 and 305). These data suggest a stable and relatively high-temperature regime in the Early Cenozoic of this Pacific region. The surface water temperature was 20–23°C in Paleocene, 21 or 22°C in middle Eocene, and 16 or 17°C in the terminal late Eocene–initial Oligocene, i.e., 4–6°C degrees lower.

Because the 20°C isotherm is the limit of distribution for recent tropical planktonic foraminifers in the Pacific (Belyaeva, 1969), it may be suggested that the Schatsky Rise region occurred during the Paleogene at the boundary of tropical and subtropical zones.

It seems tempting to correlate the Paleogene climatic changes in the Pacific and the eustatic sea-level oscillations manifested in sea transgressions and regressions (Fig. 5) in continental margins and transitional zones (Haq *et al.*, 1987).

In the Danian time, an extensive global transgression occurred, which gave rise to the large epicontinental basins of western Eurasia. The transgression caused migrations of warm-water *Eoglobigerina* and *Subbotina* into the northern areas of Europe and European Peritethys, as well as into the North Pacific marginal basins (the Koryak Upland).

The late Paleocene time was marked by the next extensive transgression, which was particularly distinct in the spacious European paleobiogeographic area from the British Isles to Kopet Dagh, and in the Far East (Paleocene deposits of northwestern Kamchatka) (Serova *et al.*, 1989). The considerable global climatic warming began at the end of the Paleocene, as evidenced by an isotopic curve for the Pacific and other parts of the World Ocean (Shackleton, 1986; Kaiho, 1991; Kennett and Stott, 1991), and by occurrences of thermophilic assemblages of mollusks in the Far East shelf and paratropical flora (the palm *Sabal*) in Kamchatka (Budantsev, 1984; Gladenkov and Shantser, 1993; Chelebaeva and Shantser, 1993). According to these data, the warming peaked in the first half of the Ypresian.

The middle–late Ypresian transgression coincided with relative cooling in the studied region.

The early Lutetian transgression occurred against the background of some temperature rise, which was reflected in the isotopic curve, the relatively warm-water character of molluscan assemblages and vegetation cover of Kamchatka (Gladenkov and Shantser, 1993; Kaiho, 1991), as well as the appearance of warm-water *Subbotina boweri*. Some researchers reported a climatic optimum at the early–middle Eocene boundary in the west Siberian plain (Volkova and Kul'kova, 1994).

The early Bartonian and early Priabonian eustatic transgressions were also accompanied by some rises in temperature (isotopic records, molluscan and floral evidence). This stimulated migrations of warm-water *Globigerinatheka, Subbotina*, and *Acarinina* into the marginal seas of the Far East province up to 60°N.

A PROBLEM OF EXOTIC TERRAINS

The establishment of long-distance (2000–2500 km) biotic migrations may provide a new approach to the co-occurrence of fossil assemblages displaying different paleogeographic characteristics. This phenomenon is often treated unreasonably as a result of coupling of exotic terrains. Closely spaced relatively warm- and cold-water assemblages in the boreal and arctic–boreal deposits do not always prove such a coupling and displacement of terrains for many hundreds and even thousands of kilometers from low to high latitudes. An impartial conclusion can be reached only through the integrated analysis of structural, biostratigraphic and paleogeographic features. When the adjoining structural–facial zones or blocks (terrains) exhibit similar fossil assemblages and similar or genetically related rock formations, the presence of exotic terrains is difficult to prove, though there are closely spaced cold- and warm-water assemblages. A possibility of warm-water assemblage migrations from south to north, i.e., a noticeable widening of the subtropical climatic zone, should be always taken into account. The widening may be combined with the corresponding reduction of the boreal zone, and this also results in the convergence of assemblages with different climatic affinity. Not adequately analyzed, this convergence is often taken as an indicator of exotic terrains, especially if faunas and floras of different types occur in areas of tectonic displacements that are interpreted as sutures between blocks. The data presented above causes us to consider such reconstructions with great caution. This is especially important for the Paleocene and Eocene investigations, because it is these periods that were recently interpreted in terms of paleomagnetic and paleotectonic reconstructions, which are not supported by lithologic and paleontologic evidence (Kovalenko, 1992; Parfenov *et al.*, 1993). Therefore, study of this problem should not be tendentious, but especially thorough and comprehensive. The above data on the Far East Paleogene suggest a simpler interpretation of the co-occurrence of warm- and cold-water biotic elements as a result of the paleobiotic migrations.

CONCLUSIONS

Some peculiarities of the revealed Paleogene migrations are very intriguing.

First, as mentioned above, they were of a considerable extent (up to 2000–2500 km).

Second, during the warming periods, the northern boundary of the tropical zone displaced northward for a lesser distance than that of the subtropical zone. The first only moved a few degrees along a latitudinal gradient, while the second moved virtually 15°–20°. In other words, during the warming periods, the warm-water area expanded at the expense of the subtropical zone, and the subtropical assemblages spread over a great territory. In the periods of relative cooling, the subtropical zone was reduced and, correspondingly, the temperate zone expanded with southward displacement of its southern boundary.

The third peculiarity is the significant rate of the migrations. In a geological sense, the migrations proceeded very rapidly (if not instantly), or, to be exact, within the time limits of a biostratigraphic zone.

The fourth peculiarity, which can be derived from the presented data, is that periods of warming and cooling were different in duration. It was already reported that the Neogene warmings were three or four times longer than coolings separating them (Gladenkov and Sinel'nikova, 1991). The Paleogene data demonstrates the same trend, although not so clearly pronounced. The Paleogene climatic pattern as a whole shows that the five mentioned periods of considerable warming were somewhat shorter than the periods of relative cooling separating them.

It is important to compare the Paleogene climatic reconstructions for the studied regions based on planktonic foraminifers with those based on benthic groups and flora. The latter (Gladenkov and Shantser, 1993) suggest three periods of considerable warming: the end of the Paleocene–beginning of the Eocene, the early Lutetian, and Bartonian–beginning of the Priabonian. During these periods (particularly, in the Bartonian–Priabonian time), some slight climatic fluctuations took place. There is no available detailed data on mollusks and flora for the Danian interval. Thus, the climatic scenarios provided by different paleontological groups appear to be similar: during the Paleogene, there were four significant climatic optima, which are likely to reflect phenomena not only of a regional, but subglobal scale.

This inference is supported by the data on the European paleobiogeographic area (the Northern Caucasus, the Kheu River section, and the Caspian syneclise) and the Atlantic Ocean (Krasgeninnikov and Muzylev, 1975; Naidin and Beniamovskii, 1994; Boersma and Premoli Silva, 1991).

In the first region, warm-water *Subbotina, Acarinina*, and *Morozovella* appeared first in the late Danian–initial late Paleocene. For the second time, warm-water *Morozovella* (*M. aequa*) appeared there, as in the Far East region, in the late Thanetian–Ypresian (in the early Ypresian, they became the most numerous: *Morozovella subbotinae, M. marginodentata*, and *M. lensiformis*). The next appearance of warm-water *Globigerinatheka* and *Hantkenina* (*G. index, H. alabamensis*, and others) was recorded here, as in the Northwest Pacific, for the late Lutetian early–Bartonian. The last Eocene invasion of warm-water plankton occurred synchronously in the North Peritethyan basin and in the North Pacific paleobiogeographic area (early Priabonian), and was expressed in the dispersal of *Globigerinatheka* forms (*G. tropicalis*, and *G. index*).

According to Boersma and Premoli Silva (1991), in the Paleocene–Eocene time, warm-water species migrated into the high latitudes of the Atlantic Ocean approximately in the same intervals of geological time, as in the Northwest Pacific, i.e., in those corresponding to zones P1d (late Danian), P3a (beginning of the late Paleocene), P5, P6–7 (late Thanetian–early Ypresian), P12 (early Bartonian), P16 (middle Priabonian).

ACKNOWLEDGMENTS

We are grateful to I.A. Basov for careful review of the manuscript and helpful remarks.

Reviewer I.A. Basov

REFERENCES

Alabusheva, A.V., First Discovery of Planktonic Foraminifers in the Danian Deposits of the Khatyrka Depression (Northeastern USSR), *Dokl. Akad. Nauk USSR*, 1989, vol. 308, no. 6, pp. 1462–1465.

Bakhteev, M.K., Beniamovskii, V.N., Bragin, N.Yu., *et al.*, New Data on Mesozoic–Cenezoic Stratigraphy of Eastern Kamchatka (the Valaginskii Ridge), *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 6, pp. 77–84.

Barinov, K.V., Late Neogene Mollusks, Detailed Stratigraphy, and Main Events in the Far East of Russia, *Cand. Sci. (Geol.–Mineral.) Dissertation*, Moscow: Geolog. Inst. Russ. Acad. Sci., 1994.

Basilyan, A.E., Vitukhin, D.I., and Oreshkina, T.V., The Upper Cenozoic of Eastern Kamchatka, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1993, vol. 68, no. 5, pp. 79–94.

Basov, I.A., Evolution of Planktonic Foraminifers of the Warm-Water Pacific in the Paleogene, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 5, pp. 72–80.

Belyaeva, N.V., Planktonic Foraminifers in the Surface Sediments of the Pacific Ocean, in *Tikhii Okean* (The Pacific Ocean), Moscow: Nauka, 1969, pp. 73–119.

Beniamovskii, V.N. and Fregatova, N.A., Stages in Development of the North Pacific Paleogene Foraminifers, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1993, vol. 68, no. 3, pp. 96–101.

Beniamovskii, V.N., Fregatova, N.A., Spirina, L.V., *et al.*, Paleogene Zones of Planktonic and Benthic Foraminifers in Eastern Kamchatka, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1992, no. 1, pp. 100–113.

Boersma, A. and Premoli Silva, I.P., Distribution of Paleogene Planktonic Foraminifera—Analogies with the Recent?, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1991, vol. 83, pp. 29–48.

Budantsev, L.Yu., The Problem of Boundary between Early and Late Cenophytes in the Northern Pacific, in *Sreda i zhizn' na rubezhe epokh kainozoya v Sibiri i na Dal'nem Vostoke* (Environments and Life at the Boundary Epoches of the Cenezoic in Siberia and the Far East), Novosibirsk: Nauka, 1984, pp. 20–24.

Chelebaeva, A.I. and Shantser, A.E., Floral Stages in the Paleogene of Kamchatka: Sequence and Active Factors, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 4, pp. 73–76.

Corfield, R.M., Patterns of Evolution in Palaeocene and Eocene Planktonic Foraminifera, in *Micropalaentology of Carbonate Environments*, British Micropalaentological Society Series, Hart, W.B., Ed., London, 1987, pp. 93–110.

Douglas, R.G. and Savin, S.M., Oxygen and Carbon Isotope Analysis of Tertiary and Cretaceous Microfossils from the Schatsky Rise and Other Sites in the North Pacific, in *Initial Reports of the DSDP*, Washington: US Gov. Print. Off., 1975, vol. 32, pp. 509–520.

Fisher, A.G., Heezen, B.C., *et al.*, *Initial Reports of Deep Sea Drilling Project*, Washington: US Gov. Print. Off., 1971, vol. 6, pp. 47–145.

Galerkin, L.I., Barash, M.S., Sapozhnikov, V.V., and Pasternak, F.A., *Tikhii okean* (The Pacific Ocean), Moscow: Mysl', 1982.

Gladenkov, Y.B., Cenozoic Palaeogeography and Climatic Change in the North Pacific, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1994, vol. 108, pp. 311–318.

Gladenkov, Yu.B., Marine Neogene Stratigraphy of the North Pacific Belt, *Tr. Geol. Inst.*, 1990, no. 428.

Gladenkov, Yu.B., Bagdasaryan, G.P., Beniamovskii, V.N., *et al.*, Paleogene Plankton in the Il'pinskii Peninsula, the Koryak Highland, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1988, no. 10, pp. 85–91.

Gladenkov, Yu.B., Barinov, K.B., Basilyan, A.E. *et al.*, Detailed Neogene Subdivisions in Kamchatka, *Tr. Geol. Inst.*, 1992, no. 478.

Gladenkov, Y.B. and Shantser, A.E., Neogene of Kamchatka: Stratigraphy and Correlation of Geological Events, *Pacific Neogene Events*, Tokyo, pp. 173–182.

Gladenkov, Yu.B. and Shantser, A.E., Paleogene Geological Events in Kamchatka, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 1, pp. 97–108.

Gladenkov, Yu.B. and Sinel'nikova, V.N., Miocene Mollusks and Climatic Optima in Kamchatka, *Tr. Geol. Inst.*, 1991, no. 453.

Gladenkov, Yu.B., Sinel'nikova, V.N., Shantser, A.E., *et al.*, The Eocene of Western Kamchatka, *Tr. Geol. Inst.*, 1991, no. 467.

Haq, B.U., Hardenbol, J., and Vail, P.R., Chronology of Fluctuating Sea Levels since the Triassic, *Science*, 1987, vol. 136, pp. 1156–1167.

Kaiho, K., Geological Ages of the Paleogene of Hokkaido, Japan, Based upon Planktonic Foraminifera, *Fossils*, 1983, vol. 34, pp. 41–49.

Kaiho, K., Global Changes of Paleogene Aerobic/Anaerobic Benthic Foraminifera and Deep-Sea Circulation, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1991, vol. 83, pp. 65–85.

Kaiho, K. and Saito, T., Terminal Cretaceous Sedimentary Sequence Recognized in Northernmost Japan Based on Planktonic Foraminiferal Evidence, *Proc. Japan Acad., Ser. B.*, 1986, vol. 62, pp. 145–148.

Kennett, J.P. and Stott, L.D., Abrupt Deep-Sea Warming, Paleooceanographic Changes and Benthic Extinctions at the End of the Palaeocene, *Nature*, 1991, vol. 353, no. 6341, pp. 225–229.

Kovalenko, D.V., Paleomagnetism of the Paleogene Complexes of the Il'pinskii Peninsula, Kamchatka, *Geotektonika*, 1992, no. 3, pp. 78–95.

Krasheninnikov, V.A., Geographic and Stratigraphic Distribution of Planktonic Foraminifers in the Paleogene of the Tropical and Subtropical Areas, *Tr. Geol. Inst.*, 1969, no. 20.

Krasheninnikov, V.A., Paleogene Planktonic Foraminifers from Deep Sea Drilling Project Leg 62 Sites and Adjacent Areas of the Northwest Pacific, in *Initial Reports of the DSDP*, Washington: US Gov. Print. Off., 1981, vol. 62, pp. 365–377.

Krasheninnikov, V.A., The Paleogene Stratigraphy of the Northwestern Pacific, *Tr. Geol. Inst.*, 1982, no. 369.

Krasheninnikov, V.A. and Muzylev, N.G., Correlation between Zonations Based on Planktonic Foraminifers and Nannoplankton in the Paleogene Sections of the Northern Caucasus, *Voprosy Mikropaleontol.*, 1975, no. 18, pp. 212–224.

Krasheninnikov, V.A., Serova, M.Ya., and Basov, I.A., Paleogene Stratigraphy and Planktonic Foraminifers from the High Latitudes of the Pacific, *Tr. Geol. Inst.*, 1988, no. 428.

Naidin, D.P. and Beniamovskii, V.N., On the Upper Limit of the Danian Stage: Article 2, Danian, Montian, and Selandian outside the Stratotype Regions, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1989, no. 1, pp. 21–38.

Naidin, D.P. and Beniamovskii, V.N., The Suvlukaya Paleogene Section (the Crimea), *Stratigr. Geol. Korrelyatsiya.*, 1994, vol. 2, no. 3, pp. 75–86.

Oreshkina, T.V., Diatoms and the Neogene Events in the Subarctic Pacific, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1993, vol. 65, no. 3, pp. 84–90.

Parfenov, L.V., Natapov, L.M., Sokolov, S.D., and Tsukanov, N.V., Terrains and Accretion Tecnonics (Northeastern Asia), *Geotektonika*, 1993, no. 1, pp. 1151–1175.

Premoli Silva, I. and Boersma, A., Atlantic Paleogene Planktonic Foraminiferal Bioprovincial Indices, *Mar. Micropaleontol.*, 1989, no. 14, pp. 357–371.

Serova, M.Ya., Paleogene Zonation and Correlation in the Northwestern Pacific Province, in *Biostratigrafiya, fauna i flora kainozoya severo-zapadnoi chasti Tikhookeanskogo podvizhnogo poyasa* (Cenozoic Biostratigraphy, Fauna, and Flora of the Northwestern Part of the Mobile Pacific Belt), Moscow: Nauka, 1969, pp. 104–114.

Serova, M.Ya., Periodical Changes in Foraminiferal Assemblages of the Open Oceanic Basins (Exemplified by the Tertiary Deposits of Kamchatka), in *Trudy VII sessii Vsesoyuznogo paleontologicheskogo obshchestva* (Proc. VII Sess. of All-Union Paleontol. Soc.), Leningrad, 1964, pp. 39–45.

Serova, M.Ya., Planktonic Foraminifers of the Paleogene and Neogene from the Northern Pacific Province, in *Voprosy Micropaleontol.*, 1978, no. 21, pp. 162–179.

Serova, M.Ya., Danilenko, L.A., Kolyada, A.A., and Petrina, N.M., Upper Cretaceous and Paleogene Subdivisions in the Koryak Highland, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1980, no. 10, pp. 186–199.

Serova, M.Ya., Fot'yanova, L.I., and Fradkina, A.F., Marine and Continental Danian–Paleocene of Northwestern Kamchatka, in *Kainozoi Dal'nego Vostoka* (The Far East Cenozoic), Vladivostok: Biol.-Pochv. Inst., 1989, pp. 186–199.

Shackleton, N.J., Paleogene Stable Isotope Events, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1986, vol. 57, pp. 91–102.

Shcherbinina, E.A., Paleogene Stratigraphy and Palaeooceanography of the Pacific Ocean according to Nannoplankton Records, *Cand. Sci. (Geol.–Mineral.) Dissertation*, Moscow: Inst. Lithosphere, 1992.

Volkova, V.S. and Kul'kova, I.A., Cenozoic Climatic Optima in Western Siberia (according to the Palynological Data), *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 1, pp. 108–112.

Volobueva, V.I., Gladenkov, Yu.B., Beniamovskii, V.N., *et al.*, *Opornyi razrez morskogo paleogena severa Dal'nego Vostoka (poluostrov Il'pinskii)* (Marine Paleogene Reference Section of the Northern Far East, the Il'pinskii Peninsula), Magadan: Sev.-Vost. Kompl. Nauch.-Issled. Inst., 1994, part 1.

Stratigraphy and Geological Correlation, Vol. 4, No. 5, 1996, pp. 496–505. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 5, 1996, pp. 83–92.
Original Russian Text Copyright © 1996 by Volkova, Kul'kova.
English Translation Copyright © 1996 by МАИК Наука/Interperiodica Publishing (Russia).

The Oligocene–Early Miocene Floral Assemblages from Western Siberia

V. S. Volkova and I. A. Kul'kova

Institute of Geology and Geophysics, Siberian Division, Russian Academy of Sciences, Universitetskii pr. 3, Novosibirsk, 630090 Russia

Received November 28, 1994

Abstract—The results of research show that the main geologic events Western Siberia at the end of the Eocene occurred in a succession of negative and positive tectonic movements that brought about regression of the basin. The climate cooling caused the extinction of subtropical flora and the replacement of the evergreen forests by the coniferous. In the Oligocene, the climate was the principal factor in biota evolution, and the vegetation developed in two stages. During the first stage, i.e., in the early–middle Oligocene (the Atlym–Novomikhailovskoe time), the coniferous dominated in the mixed coniferous–broad-leaved forests. In the course of the second stage, i.e., in the late Oligocene–early Miocene (the Turtass and Abrosimovka time), the Turtass flora included subtropical plants. The continental sedimentation was typical of both stages. According to paleobotanical data, there were no significant reorganizations in the vegetal biota at the late Oligocene–early Miocene interface. Consequently, the palynological data are insufficient to draw a boundary between the Turtass and Abrosimovka formations.

Key words: *West Siberia, Oligocene, early Miocene, Atlym, Novomikhailovskoe, Turtass, Abrosimovka horizons, flora, pollen assemblages.*

In West Siberia, the Oligocene and lower Miocene deposits often occur as horizons, whose thickness and lithology depend on their confinement to various facies zones (Shatskii *et al.*, 1973). On the larger part of the territory, the Oligocene and lower Miocene deposits are overlain by the thick upper Neogene and Quaternary deposits except in the lower reaches of the Irtysh and Ob' rivers north of Khanty Mansiisk and in the middle course of the Tavda River, where the Oligocene and lower Miocene continental deposits are exposed above the water edge (Volkova, 1966; Shatskii *et al.*, 1973).

The recent middle-scale geological survey and drilling facies produced the latest observation data on the Kolpashevo–Aleksandrovskoe (Kriventsov, 1984; Goloverov *et al.*, 1984) and Khanty Mansiisk (Vlasov and Cherepanov, 1984) facies zones (Fig. 1). The new data greatly contributed to our knowledge of lithofacies and biota characteristics of the Paleogene horizons mentioned above. In the 1990s, the palynology of these horizons was studied from core samples at the Institute of Geology and Geophysics, Siberian Division, Russian Academy of Sciences, under the State Scientific-Technical Program of Russia "Recent Environmental and Cimatic Changes." The study of microphytofossils has established the critical periods in biota evolution as concurrent with global and regional reorganizations in paleogeography and paleoclimate, and has determined sedimentation cycles along with volumes and boundaries of horizons. In this paper, we briefly discuss the main paleogeographic events by using materials published earlier (Panova, 1971; Kul'kova, 1981; Lyubomirova, 1985) and palynological data recently obtained.

THE LATE EOCENE

Since the end of the late Eocene, the differentiated tectonic movements were fairly active in the territory of Western Siberia. In the larger part of the plain south of 64°N, the moderate negative movements in the central area kept the shallow Tavda water basin in existence. By that time, the connection with the World Ocean in the north was already closed, and the sea basin was open to the Tethys only through the Turgai Strait. The northern part of the plain was thus transformed into the denudation–accumulation plain, while the central part accumulated marine deposits of the Tavda Formation. According to Vlasov and Cherepanov (1984), the upper Eocene Tavda Formation comprises two subformations. The lower one is composed of green and grayish-green platy silts and montmorillonite pelites with thin sand and silt streaks. The thickness of the deposits varies from 20 to 70 m, and the rocks contain pyrite, fragments of shells, fish remains, coalified detritus, and rare foraminifer shells.

The upper Tavda Subformation is composed of green and greenish-gray silty clays with sand–silt lenses. The main components of the clayey fraction are

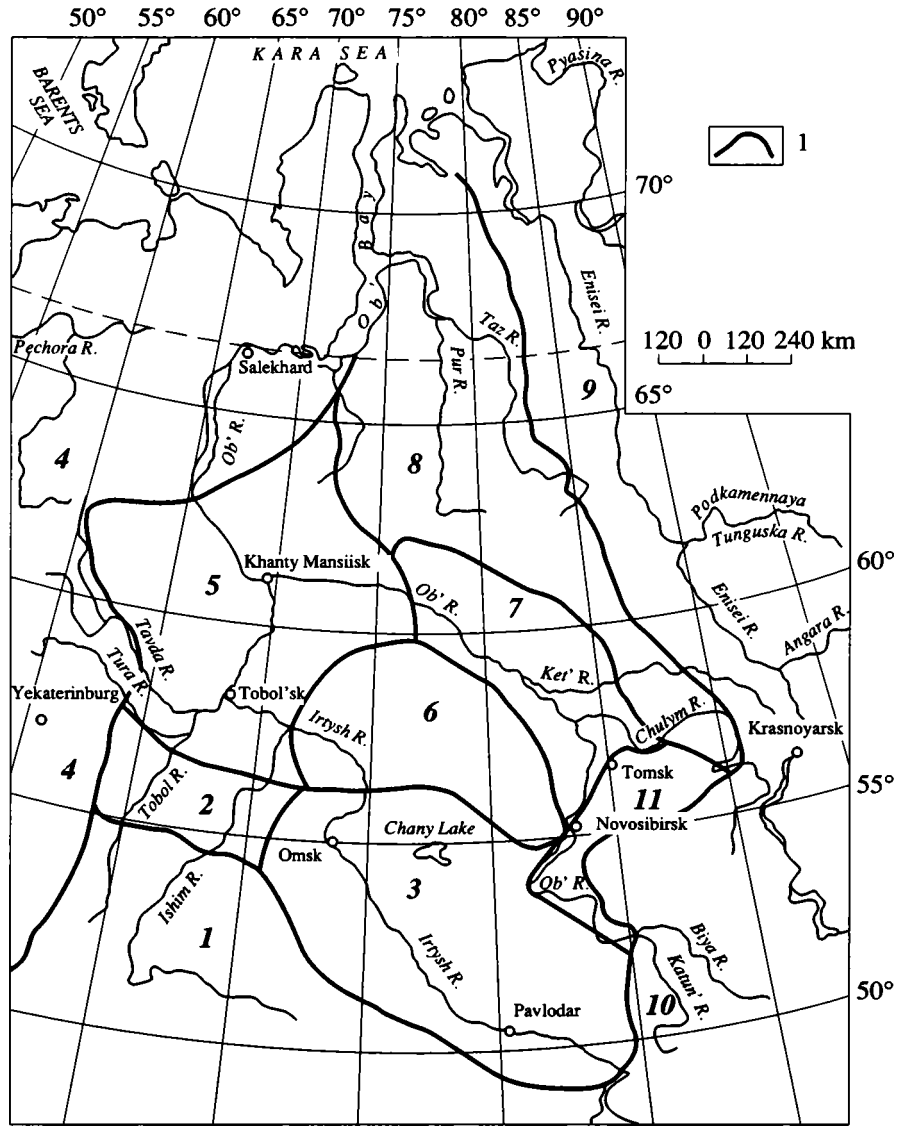


Fig. 1. Zonation scheme of the Paleogene and Neogene continental deposits in the West Siberian lowland.
Facies zones: (*1*) Kazakhstan; (*2*) Ishim; (*3*) Kulunda–Barabinsk; (*4*) Eastern Urals area; (*5*) Khanty Mansiisk; (*6*) Tara–Vasyugan'; (*7*) Kolpashevo–Aleksandrovskoe; (*8*) Pur–Ket'; (*9*) Enisei; (*10*) Altai; (*11*) Tomsk; 1—boundaries of facies zones.

montmorillonite with hydromica and, less often, beidellite. The top of the Tavda Formation is uneven, and the elevation marks vary from 75 to 250 m (Fig. 2). According to some researchers (Vlasov and Cherepanov, 1984), benches of different height were formed as a result of the continuous–intermittent character of the Tavda Sea regression, but without any influence from the structural plan.

The paleontology of the Tavda Formation is poor. The deposits yielded occasional calcareous foraminifers of the *Cribroelphidium reschtamicum* zone, ostracod remains, and imprints of the water fern *Azolla vera*. Kul'kova recently studied the cysts of protozoan dinoflagellate algae in the samples recovered from several holes drilled in the Khanty Mansiisk facies zone, and the age of the formation was redefined (Kul'kova and Shatskii, 1990). A correlation of the dinoflagellate zones with the nanoplankton zones of Europe indicates that, by nanoplankton evidence, the Tavda Formation corresponds to the zones from 15 to 21, and its origin can be timed by Middle–late Eocene. According to the West Siberian Stratigraphic Scale, adopted at the Interdepartmental Meeting in Tyumen' in 1976, the Tavda Formation is dated as late Eocene–early Oligocene.

The palynological data for the Tavda Formation show that its palynoflora was already subtropical in the late Eocene, and considerably differed from the floras of the early Oligocene (Lyubomirova, 1975; Kul'kova, 1981, 1984; Panova, 1971). The late Eocene floras were mostly composed of various formal taxa and

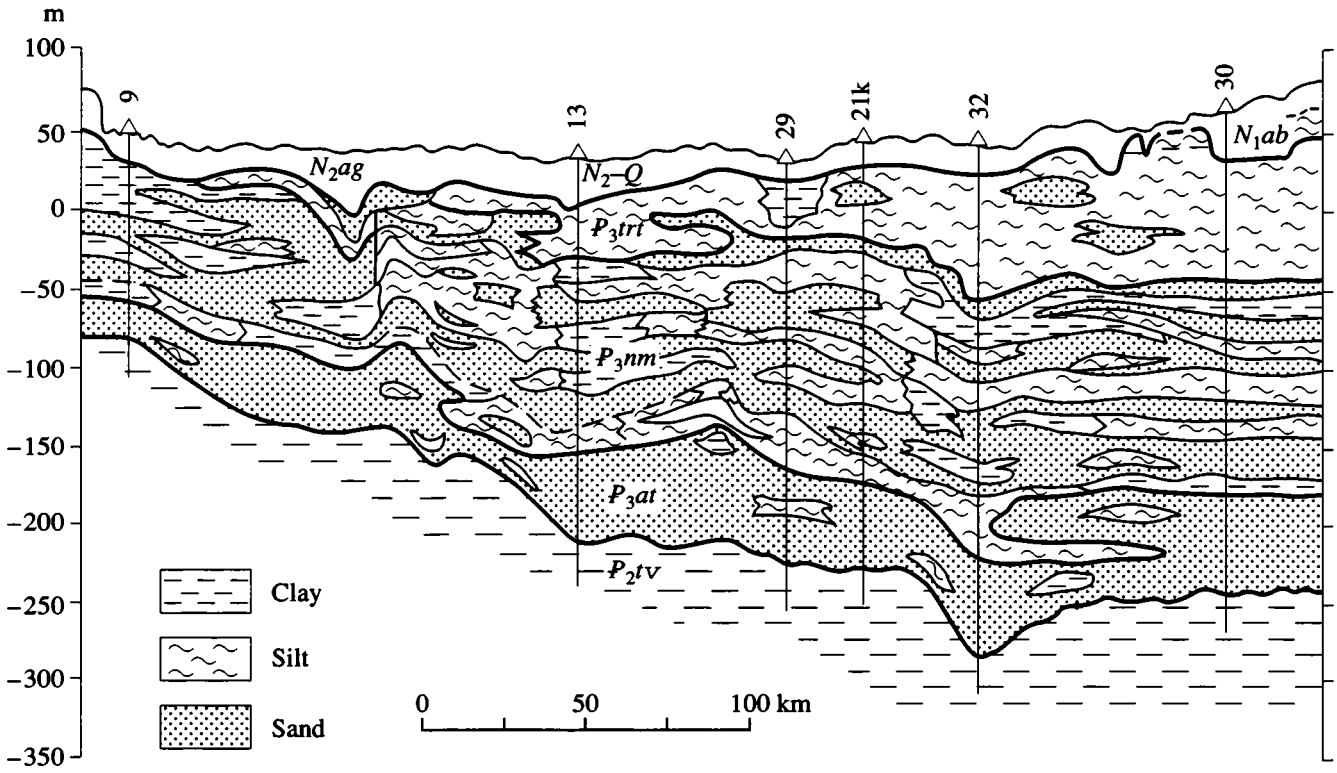


Fig. 2. Schematic Paleogene cross section in area between the Konda and Dem'yanka rivers (after Vlasov and Cherepanov, 1984). Indices in the figure denote Paleogene and Neogene formations of Western Siberia (see text).

angiosperms, among them plants producing small tricolpate and tricolpate–pored pollen of Fagaceae, Araliaceae, Sterculiaceae, Anacardiaceae, and Nyssaceae. The most diverse are Fagaceae, *Castanopsis, Castanea,* and *Lithocarpus*. By the end of the late Eocene, the abundance of *Castanopsis* was reduced, and the vegetal communities acquired many plants producing pollen typical of ancient evergreen oaks *Quercus gracilis* Boitz, and *Q. graciliformis* Boitz, *Tricolporopollenites librarensis* Th. et Pfl.; Fig. 3 shows the distribution of plant assemblages.

As the climate cooled at the Eocene–Oligocene boundary, Palmae disappeared, the share of thermophilic *Juglans, Carya, Pterocarya,* and Ulmaceae was reduced, and conifer covered considerable areas only in the piedmont areas.

THE EARLY OLIGOCENE

The early Oligocene was the time of cardinal transformation of the entire paleogeographic environment owing to the changes in the tectonic regime. At that period, the northern part of Asia experienced irregular tectonic upheavals that caused gradual regression of the sea basin. According to recent data, the direction of linear erosion in the Tavda Formation correlates with the grid of the main tectonic lineaments (Vlasov and Cherepanov, 1984). The onset of the early Oligocene launched a different tectonic regime in Western Siberia, and the continental sedimentation was set in.

In the early Oligocene, the fluvial network extensively developed. The alluvial and partly limnetic deposits of the Atlym Formation are represented by white quartz fine-grained sands observed in natural outcrops and boreholes. The sands contain occasional lenses and interbeds of poorly sorted inequigranular to coarse varieties, in which the coarse fractions are composed of white quartz. The sands often have remains of lignite wood. Several sand sequences show lenses and intercalations of hydromicaceous kaolin clays. The Atlym Formation is 5 to 50 m thick, and common in the Khanty Mansiisk and Kolpashevo–Aleksandrovskoe facies zones. In the Konda and Dem'yanka river basins, the formation overlies relief benches of the Tavda time at different absolute marks varying from 70 to 250 m (Fig. 2). The lower boundary is distincty defined, and often marked by basal layers of gravel and pebbles. The upper boundary is vague, and in all facies zones it is drawn conditionally at different levels according to the presence of laterally limited interbeds of clays and loams. They are embedded in the sands and sandy loams of the overlying Novomikhailovskoe Formation, which is clearly identified in the borehole cores from the Konda River basin (Fig. 2). The Novomikhailovskoe Formation is coeval with the Atlym Forma-

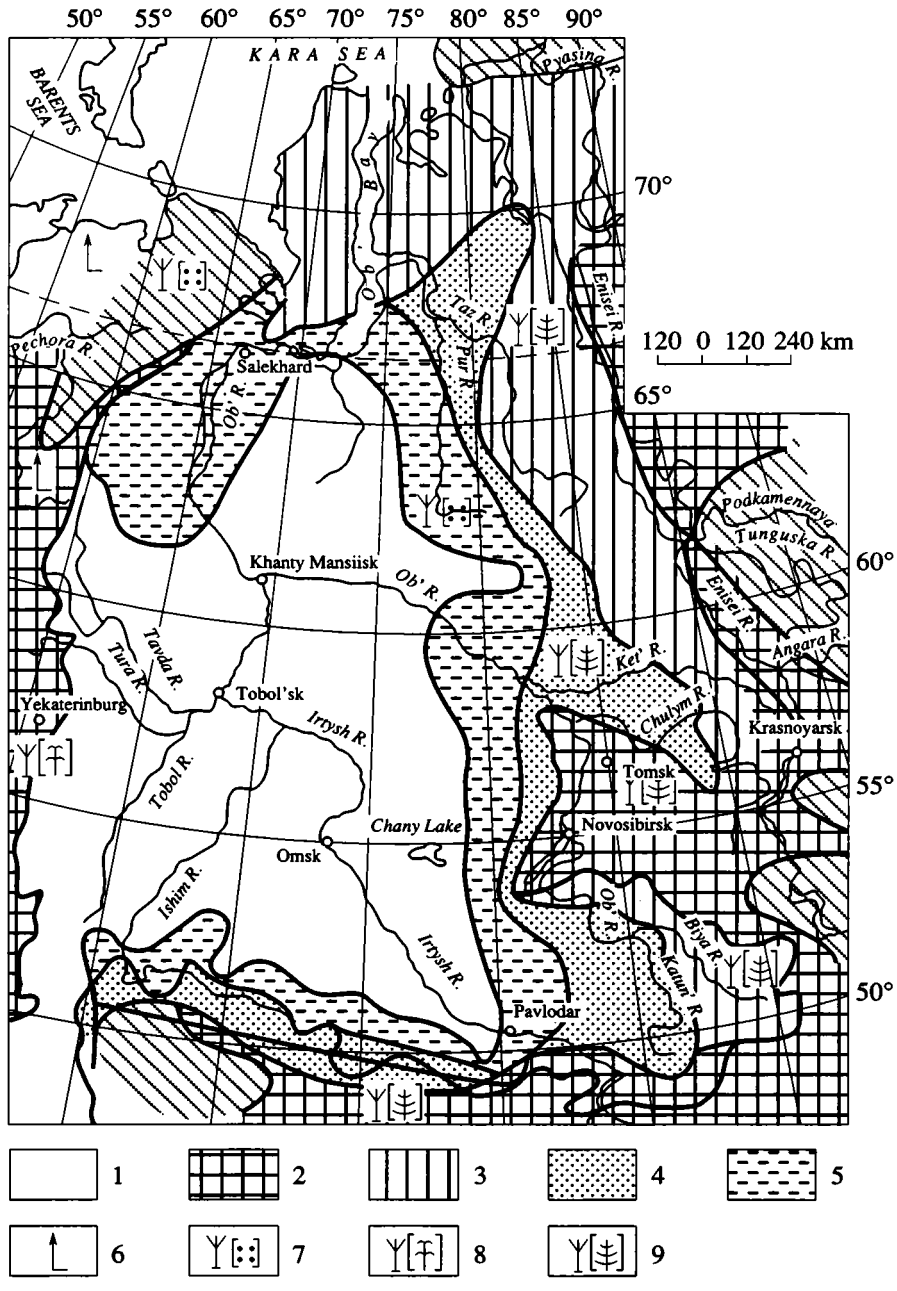


Fig. 3. Schematic paleogeographic map for the terminal Eocene (the distribution of relief types after Arkhipov *et al.*, 1970): (1) Submarine plains; (2) hilly plains above the Paleozoic basement; (3) hilly plains above the unconsolidated Mesozoic basement; (4) limnetic–alluvial plains; (5) coastal and lagoon–delta plains periodically flooded by the sea; (6) mountain vegetation composed of various species of pines and spruces; (7) forest evergreen vegetation with the dominance of Taxodiaceae; (8) leaf evergreen forests with palms; (9) coniferous and evergreen leaf forests with *Podocarpus*.

tion and dated as the early–middle Oligocene according to the stratigraphic scheme of Western Siberia.

We should note, however, that the Novomikhailovskoe Formation marks a transition from the fluvial to the limnetic and limnetic–swamp sedimentation which indicates a rather quiescent tectonic setting.

The Novomikhailovskoe Formation is composed of more clayey than sandy rocks, and its upper part encloses layers of brown coals 5 to 10 m thick (Shatskii *et al.*, 1973). The coal-bearing capacity of the formation varies and is higher on the slopes of prominent structures, particularly in the Tara–Vasyugan and Kolpashevo–Aleksandrovskoe facies zones. The thickness varies from 80 to 100 m.

The Atlym and Novomikhailovskoe formations have similar compositions of the heavy fraction, and in both the

ore minerals (up to 55%) and the epidote–zoisite group (17–45%) dominate. Leucoxene, apatite, garnet, and tourmaline were found in close proportions (1 to 5%); the zircon content is higher (up to 10%). There are green hornblende and sporadic authigenic minerals: siderite, pyrite, marcasite, and limonite. Vegetal detritus is a common ingredient composing up to 100% of the fine fraction in individual samples. The large amount of organic material and authigenic minerals is a typical feature of limnetic deposits of the Novomikhailovskoe Formation.

Climatic fluctuations were an important factor for the vegetal biota in the first half of the Oligocene. A considerable drop in the air temperature during July and January, and in its mean annual values during the early Oligocene (the Atlym time) caused the extensive growth of Pinaceae, Taxodiaceae, and *Picea*, which require similar environments. The same pollen relationship between these groups was observed in the Novomikhailovskoe Formation. Here, the dominant plants are *Pinus coraiensis* Zakl., *P. cembraeiformis* Zakl., *P. sibiriciformis* Zakl., and *P. strobiformis* Zakl. A certain amount of *Abies,* and *Picea* pollen is present. Among the angiosperms, Juglandaceae with prevalent *Carya spackmania* Trav. and Betulaceae dominate. The pollen of *Quercus* cf. *glauca* Pan., *Q. gracilis*, *Q. graciliformis,* and *Castanopsis* is persistently present, as is that of the subtropical *Palmae, Myrtea, Rhus*, and others. On the basis of this palynologic data, Panova (1971) established the so-called *Carya spackmania* assemblage. Its composition varies over the area, and is most complete in the sequences of the Kulunda–Barabinsk facies zone. North of the zone, in the basin of the Tara and Vasyugan rivers, it is superseded by another assemblage with the dominant *Myrica, Quercus, Betula,* and *Juglans* species. The *Q. spackmania* pollen is scarce, while the abundance of *Picea* grows in the coniferous forests of the Novosibirsk Ob' area, as does the amount of pollen of *Carpinus perfectus* Pan. and various *Liquidambar* species among the angiosperms.

The data on palynoflora, derived from the numerous boreholes, show that there is no great difference between the Atlym and Novomikhailovskoe floras.

By the end of the middle Oligocene (the Novomikhailovskoe Formation), the tectonic movements produced a vast limnetic, partly alluvial plain that covered the entire central part of western Siberia (Arkhipov *et al.*, 1970) (Fig. 4). In the west and east, the plain was bounded by a narrow denudation–accumulation plain that, in turn, merged into the denudation plain.

Numerous palynologic remains were recovered from the cores of boreholes drilled north and south of the latitudinal stretch of the Ob' watercourse and in the lower reaches of the Pur River. They indicate that, in the Novomikhailovskoe time, the territory of the swamped accumulation plain was covered with coniferous–broad-leaved forests with birches *Betula gracilis*. The central part of the plain was overgrown with Taxodiaceae forests and the subtropical plants Palmae, *Myrtea, Rhus,* and *Magnolia.* In the denudation–accumulation areas, the polydominant forests included various species of pines, while the uplands and low mountains on the plateau were overgrown with spruces, firs, tsugas, and pines.

THE LATE OLIGOCENE

At the beginning of the late Oligocene, in the central part of the plain, a large closed lake appeared as a result of reorganization of the structural plan. The basin again started to accumulate limnetic sediments, described in the literature as the Turtass Formation, which now composes the Khanty Mansiisk and Tara–Vasyugan facies zones (greenish-gray finely stratified silts). The surface of the formation lies at a depth of 50 to 120 m. In river valleys and on the arches of positive structures, the upper horizons of the Turtass Formation are exposed at the surface. The outcrops of the Turtass Formation were studied in the lower reaches of the Irtysh River (Volkova and Panova, 1964), along the Uie River, in the region of the Koshkul' Village (Volkova and Kul'kova, 1984), and in the Turtass River valley. Unlike the underlying Novomikhailovskoe Formation, the Turtass Formation has no coals, and overlies the former above an erosion surface and occasional angular disconformity (the Irtysh River outcrops near the Missiya Village). Both formations are covered by the Abrosimovka Formation containing brown coals.

The larger part of the Turtass Formation is composed of thin horizontally banded silt layers with intermittent fine streaks of sand. The formation is 50 to 75 m thick and characterized by stable facies and mineral compositions, it bears diatom algae and radiolarians. Based on the fine horizontal stratification in rocks and the large area they cover, Shatskii concluded that the Turtass Formation has accumulated in a shallow limnetic basin, probably of a marine affinity. The paleontological data, however, do not confirm their marine genesis. The late Oligocene age of the formation is substantiated by the gastropod and viviparid fauna, the freshwater diatom flora, and abundant pollen and spore assemblages (Panova, 1971) with *Fagus grandifoliformis*. In the deposits of the North Aral area, the assemblage contains the mollusks *Cardium abundas* indicative of the Chattian Stage in Western Europe (Korobkov, 1965). The pollen assemblage of the Turtass Formation includes abundant grains of many pine species (Volkova and Panova, 1964; Panova, 1974), a certain amount of different *Podocarpus*, and new species of *Platycarya, Betula* (*B. suberecta* Pan.), *Carpinus duinensiformis* Pan., *Corylus sibirica* Pan., and *C. bifurcata* Pan. The amount of *Ulmus* and Fagaceae pollen grows in contrast to the spectra of the Atlym and Novomikhailovskoe formations. As in the Eocene, this pollen dominates. The appearance of the new *Quercus, Fagus,* and *Castanea* species is a characteristic feature; by its morphology, their pollen is already close to that of present genera.

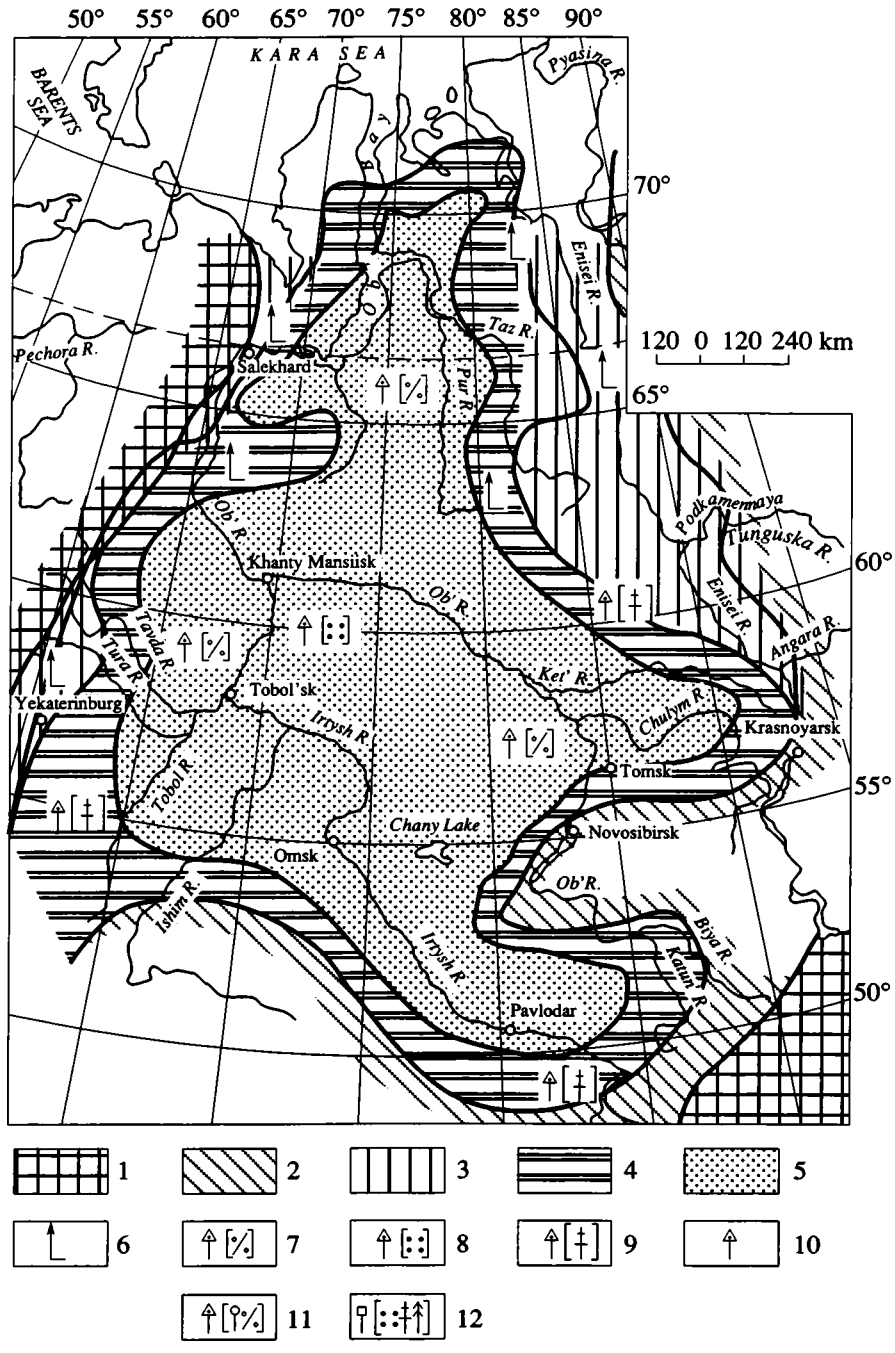


Fig. 4. Schematic paleogeographic map for the middle Oligocene (the Novomikhailovskoe time).

(1) medium-height plateaux and low mountains; (2) low plateau; (3) denudation plains; (4) denudation–accumulation plains; (5) accumulation plains, after Nikolaev (Arkhipov *et al.*, 1970); (6) mountain forest vegetation; (7) coniferous–broad-leaved forests with birch; (8) forests of humid subtropics with Taxodiaceae; (9) polydominant coniferous–broad-leaved forests with pines; (10) polydominant coniferous–broad-leaved forests; (11) coniferous–broad-leaved forests with *Juglans, Ulmus,* and *Betula*; (12) broad-leaved forests with Taxodiaceae, pines, spruces.

The most typical forms, after Panova, are *Fagus grandifoliformis* Pan., *Canstanea,* and *Castanopsis*. The variety of subtropical plants changes with the appearance of *Liquidambar mangelsdorfiana* Pan., *Nyssa rotunda* Pan. and *Ilex obscuriacostata* Pan. species. Persistently present are grasses, the bog and shrub plants *Spargagium, Potamogeton, Trapa*, Ericaceae, Chenopodiaceae, and Compositae. The composition of flora on the plain was typical of the Turgai vegetation of polydominant and diverse coniferous–broad-leaved forests. In the north of the Turtass accumulation plain and on its margins, the polydominant coniferous–

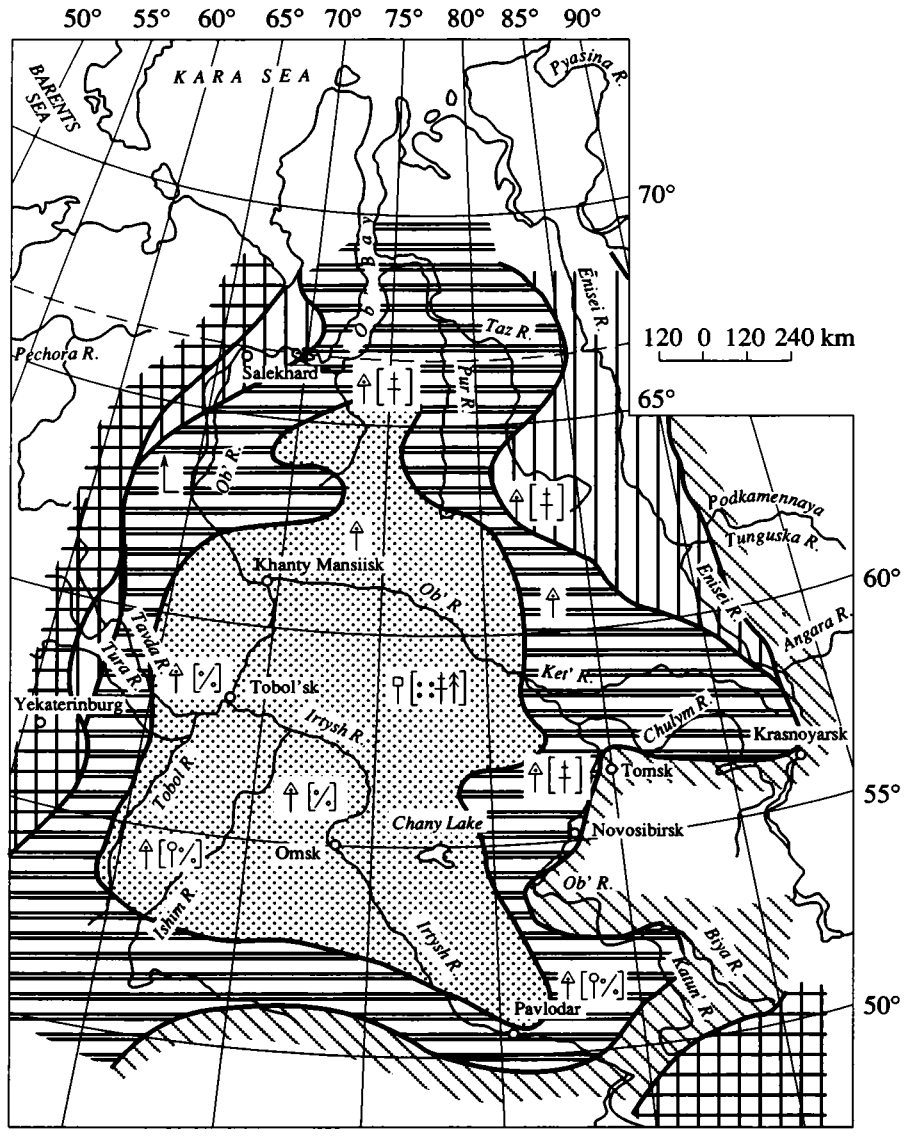


Fig. 5. Schematic paleogeographyic map for the late Oligocene (the Turtass time). See Legend to Fig. 4.

broad-leaved forests included a wide variety of pine species. The denudation–accumulation areas of the plain were covered with mountain forests of spruces, podocarpuses, pines, and birches. South of the latitudinal stretch of the Ob', the marshy broad-leaved forests included subtropical plants and abundant Taxodiaceae. In the Omsk–Tara Irtysh, Kulunda and Novosibirsk Ob' areas, the coniferous–broad-leaved forests were prevalent with *Juglans, Ulmus, Betula* (Fig. 5) and a considerable number of *Fagus, Quercus, Castanea, Platycaria* and other mesothermophilic plants. Climatic conditions were fairly warm. The temperatures in January and July, and its mean annual values were higher than in the early Oligocene by 4°, 6° and 2°, respectively. The deviations from the values of today grew from the south to the north. At the end of the late Oligocene, the vast Turtass basin started to recede.

THE EARLY MIOCENE

In the early Miocene, parts of the plain were swamped, and the accumulation of peat and coal began. In the literature, the limnetic clays with brown coal intercalations are known as the Abrosimovka Horizon (the early upper Turtass and the upper Znamenka subformations). According to the latest unified scale of 1976, the Abrosimovka Horizon corresponds to lower Miocene as a probable analog to the Aquitanian Stage. A study on the palynofloras indicates that in its complete volume, the Abrosimovka Horizon is found neither in boreholes, nor in natural rock outcrops (Nikitin, 1984; Volkova and Kul'kova, 1984). The horizon is composed of layers with certain types of floras identified as the Lyamin, Ekaterininskoe, Vasyugan and Kireevskoe assemblages. Martynov (1984) notes that particular sections have one or two strata that correlate

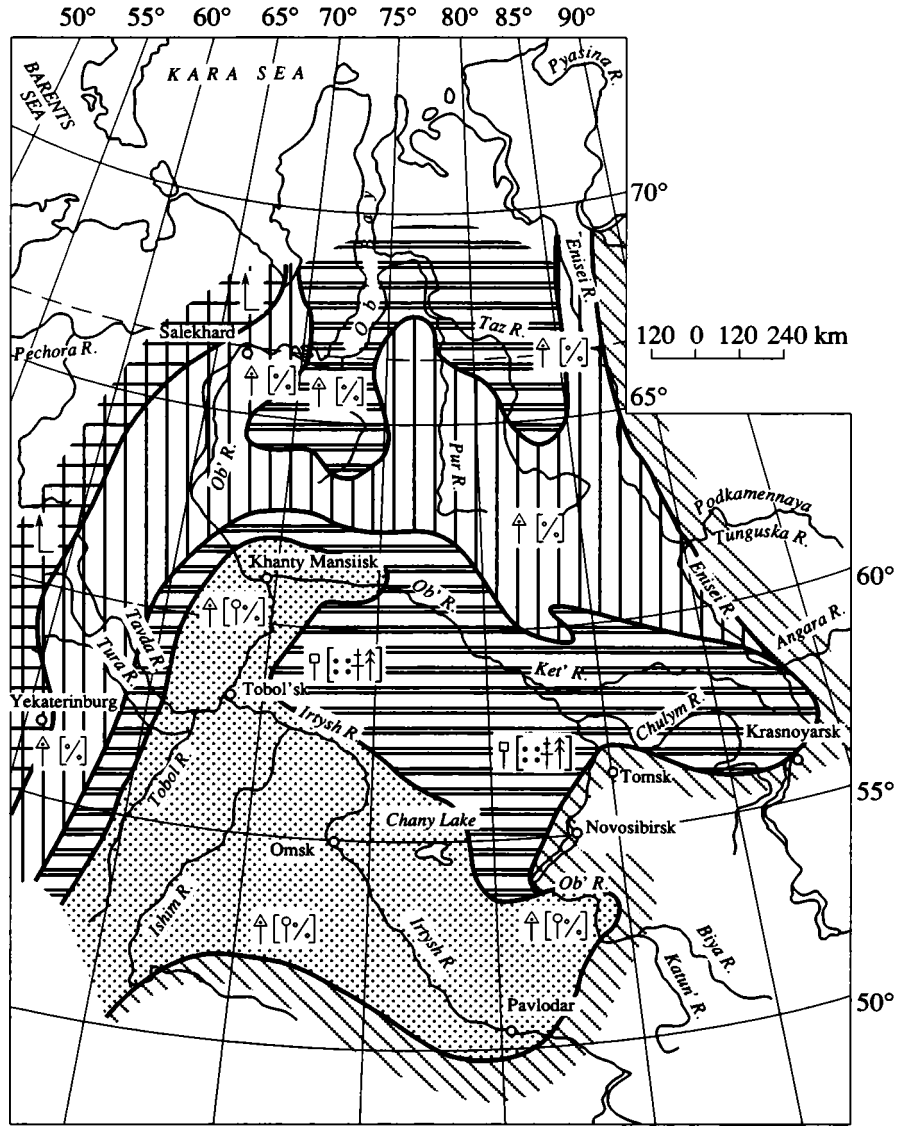


Fig. 6. Schematic paleogeographic map for the late Oligocene–early Miocene (the Abrosimovka time). See Legend to Fig. 4.

with the Abrosimovka Formation. Therefore, the stratotype of the horizon, and perhaps of the formation as well, can be composed of certain parts of sections studied in such localities as the Irtysh River, Ekaterininskoe Village, the Abrosimovka, Vasyugan, and Lyamin rivers, and Kireevskoe Village on the Ob'. We have studied floras from all localities except the Lyamin River. Moreover, in recent years, the samples recovered from numerous boreholes drilled in the Khanty Mansiisk, Tara–Vasyugan and Aleksandrovskoe–Kolpashevo areas were also studied in detail. Similar to the Turtass Formation, the assemblages contain mainly the pollen of coniferous and broad-leaved mesophilic plants of the Turgai type. As a result, the lower boundary of the Abrosimovka Formation cannot be defined as usual, when palynologists try to determine it by the pollen and spore assemblages. This difficulty implies that the climates in the early Miocene and late Oligocene were almost identical and warm enough for the broad-leaved flora.

In the spectra, the pollen of Ulmaceae and different *Quercus* species dominates, particularly that of *Quercus sibirica* Pan., after which Panova named this assemblage. Invariably present is pollen of *Quercus alnifoliformis* Pan., *Q. williamsoniana* Pan., *Q. mira* Pan., *Castanea, Platycarya, Carya glabraeformis* Pan., *Alnus, Betula gracilis* Pan., *B. suberecta* Pan., *Carpinus duinensiformis* Pan., *Corylus,* different species of *Juglans, and Pterocarya*, subtropical *Liquidambar, Ilex* sp., and *Nyssa* sp., grasses, *Sparganium* sp., Chenopodiaceae, Polygonaceae, *Diervilla*, Ericaceae, and Compositae. Among the sporulating plants, the content of spores of *Sphagnum*, Polypodiaceae, and Osmun-

daceae increases. There are single finds of spores of *Schizaea* sp. and *Lygodium* sp.

A period of relative warming during the Abrosimovka time was marked by a higer precipitation, but the species spectrum remained almost the same. The Turtass and Abrosimovka floras differ only in the quantity of pollen of *Quercus sibirica, Liquidambar, Ilex* sp., and *Nyssa* sp. However, the amount of pollen of *Castanea, Platycarya, Carya glabraeformis,* and *Fagus* is reduced.

The flora of the Kireevka type in the Abrosimovka Horizon is distinguished by the dominance of pollen of *Juglans* (up to 10–19%), *Quercus* (up to 17%), and *Fagus*.

It also included abundant *Betula* and *Alnus*, and the vegetation resembled the Canadian birch and nut-tree forests with oaks and beeches (Volkova and Kul'kova, 1984). On the whole, the Abrosimovka period is characterized by coniferous–broad-leaved and broad-leaved forests, but still with the admixture of subtropical and hydrophilic plants and holophytes (Fig. 6).

There is a well-defined boundary between the Abrosimovka Horizon and overlying middle Miocene beds of the Beshcheul Formation. By the middle Miocene time, the higher activity of neotectonic movements revived the fluvial processes. The Beshcheul Formation is composed of alternating beds of inequigranular white and yellowish-white quartz sands with brownish yellow loam streaks, and the sediments resemble banded "chipmunk" skin. At this time, a change occurred both in the facies and in the palynological assemblages (Aleksandrova, 1979).

The pollen assemblage with *Alnus* and Polypodiaceae was established for the Beshcheul Formation. The assemblage has a notably larger amount of *Alnus, Betula* and Polypodiaceae pollen. The number of various species of *Juglans, Carya, Carinus,* and *Quercus* is reduced, whereas that of aquatic bog plants *Sparganium*, Numphaceae, Polygonaceae, Compositae, and *Ericales* grows. The sharp change in biota composition was provoked by cooling.

CONCLUSION

Palynological analyses suggests several conclusions about the structure and composition of sedimentary layers of the region. The general upheaval of the entirety of northern Asia at the Eocene–Oligocene boundary changed the marine sedimentation to continental. In western Siberia, the early Oligocene period launched a new tectonic cycle of the uplift of the plain and more intensive fluvial processes. A concurrent cooling caused the subtropical type of deciduous and evergreen forests to give way to coniferous–broad-leaved forests that existed throughout the middle Oligocene (the Novomikhailovskoe time). The structure of deposits, their similar mineralogical composition, the change from the fluvial to limnetic and limnetic–bog sediments, and the similarity of palynological assemblages indicate that the Atlym and Novomikhailovskoe horizons represent a single sedimentary stage that existed during the early and middle Oligocene.

The second stage likewise covers the Turtass and Abrosimovka horizons. The structure of the sections shows a transition from the limnetic–fluvial and limnetic sediments (the Turtass Formation) to limnetic–bog sediments with brown coal beds. These two horizons also correspond to the completed sedimentary stage. The palynological data do not imply a sudden transformation in vegetation at the late Oligocene–early Miocene boundary (the Abrosimovka Formation). It is more logical, therefore, to time the Abrosimovka Formation as the late Oligocene in age and the Beshcheul Horizon as coeval to the beginning of the early Miocene. The Abrosimovka–Beshcheul boundary also marks a change in sedimentation, in this case from limnetic–bog back to fluvial, and significant reformations in floras. The boundary between these horizons is distinctly defined owing to the considerable cooling that occurred at that time which greatly affected vegetal biota.

Reviewer Yu.B. Gladenkov

REFERENCES

Aleksandrova, A.V., Palynological Substantiation of the Eocene–Early Miocene Stratigraphy in the Tomsk Ob' Area, in *Stratigrafiya i palinologiya mezozoya i kainozoya Sibiri* (The Mesozoic and Cenozoic Stratigraphy and Palynology of Siberia), Novosibirsk: Nauka, 1979, pp. 99–114.

Arkhipov, S.A., Vdovin, V.V., Mizerov, B.V., and Nikolaev, V.A., The West Siberian Plain, in *Istoriya razvitiya rel'efa Sibiri i Dal'nego Vostoka* (The History of the Development of the Relief in Siberia and the Far East), Moscow: Nauka, 1970, p. 277.

Goloverov, A.G., Kostesha, O.N., Il'inok, L.L., *et al.*, The Paleogene in the Middle Course of the Chulym River, in *Sreda i zhizn' na rubezhakh epokh kainozoya Sibiri i Dal'nego Vostoka* (Environment and Life at the Boundaries between Cenozoic Epochs in Siberia and the Far East), Novosibirsk: Nauka, 1984, pp. 82–100.

Korobkov, A.I., The Stratigraphy of the Oligocene Deposits of Northern Ust'urt and the North Aral Area from the Mollusk Evidence, *Cand. Sci. (Geol.–Mineral) Dissertation*, Leningrad: Vses. Geol. Inst., 1965.

Kriventsov, A.V., The Marine Paleogene of the Eastern Part of the Ob'–Irtysh Interfluve, in *Sreda i zhizn' na rubezhakh epokh kainozoya Sibiri i Dal'nego Vostoka* (Environment and Life at the Boundaries between Cenozoic Epochs in Siberia and the Far East), Novosibirsk: Nauka, 1984, pp. 87–92.

Kul'kova, I.A., Compositional Changes in Palynoflora of Siberia at the Eocene—Oligocene Boundary, in *Sreda i zhizn' na rubezhakh epokh kainozoya Sibiri i Dal'nego Vostoka* (Environment and Life at the Boundaries between Cenozoic Epochs of Siberia and the Far East), Novosibirsk: Nauka, 1984, pp. 51–54.

Kul'kova, I.A., The Paleogene Palynostratigraphy and Palynofloras from the Siberian Platform, Southern Part of West-

ern Siberia, and Northern Kazakhstan, in *Mezozoi i kainozoi Sibiri i Dal'nego Vostoka* (The Mesozoic and Cenozoic of Siberia and the Far East), Novosibirsk: Nauka, 1981, pp. 180–184.

Kul'kova, I.A. and Shatskii, S.B., Zonal Subdivision of the Marine Paleogene in the West Siberian Plain from the Dinocyst Evidence, *Geol. Geofiz.*, 1990, no. 1, pp. 25–30.

Lyubomirova, K.A., The Paleogene Period, in *Paleofitogeografiya Severa SSSR v melu i paleogene* (The Paleophytogeography of the Northern USSR in the Cretaceous and Paleogene), Leningrad: Nedra, 1985.

Martynov, V.A., Natural Environments and Geological Boundaries of the Neogene in Siberia, in *Sreda i zhizn' na rubezhakh epokh kainozoya Sibiri i Dal'nego Vostoka* (Environment and Life at the Boundaries of Cenozoic Epochs in Siberia and the Far East), Novosibirsk: Nauka, 1984, pp. 151–158.

Nikitin, V.P., The Miocene Floras from Western Siberia (Materials of Paleocarpological Research), in *Sreda i zhizn' na rubezhakh epokh kainozoya Sibiri i Dal'nego Vostoka* (Environment and Life at the Boundaries between Cenozoic Epochs in Siberia and the Far East), Novosibirsk: Nauka, 1984, pp. 146–151.

Panova, L.A., The Oligocene of West Siberia, in *Kainozoiskie flory Sibiri po palinologicheskim dannym* (The Cenozoic Floras of Siberia from Palynological Evidence), Moscow: Nauka, 1971, pp. 40–60.

Shatskii, S.B., Aleksandrova, L.V., Bogdanov, V.A., *et al.*, The Paleogene of the Central Western Siberia, in *Morskoi i kontinental'nyi paleogen Sibiri* (Marine and Continental Paleogene of Siberia), Novosibirsk: Nauka, 1973, pp. 4–56.

Vlasov, A.I. and Cherepanov, Yu.P., The Paleogene Stratigraphy in the Lower Reaches of the Irtysh River, in *Sreda i zhizn' na rubezhakh epokh kainozoya Sibiri i Dal'nego Vostoka* (Environment and Life at the Boundaries between Cenozoic Epochs in Siberia and the Far East), Novosibirsk: Nauka, 1984, pp. 82–87.

Volkova, V.S., *Chetvertichnye otlozheniya Nizov'ev Irtysha i ikh biostratigraficheskaya kharacteristika* (The Quaternary Deposits in the Lower Reaches of the Irtysh River and Their Biostratigraphy), Novosibirsk: Nauka, 1966.

Volkova, V.S. and Panova, L.A., The Structure and Palynology of the Principal Sequences on the Right-Hand Bank in the Lower Reaches of the Irtysh River, *Tr. Inst. Geol. Geofiz. Sib. Otd. Akad. Nauk SSSR*, 1964, no. 44, pp. 56–96.

Volkova, V.S. and Kul'kova, I.A., Compositional Changes in the Late Cenozoic Palynoflora of Siberia, in *Sreda i zhizn' na rubezhakh epokh kainozoya Sibiri i Dal'nego Vostoka* (Environment and Life at the Boundaries between Cenozoic Epochs in Siberia and the Far East), Novosibirsk: Nauka, 1984, pp. 54–62.

Stratigraphy and Geological Correlation, Vol. 4, No. 5, 1996, pp. 506–513. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 5, 1996, pp. 93–101.
Original Russian Text Copyright © 1996 by Zhamoida.
English Translation Copyright © 1996 by МАИК Наука/Interperiodica Publishing (Russia).

Second Edition of the International Stratigraphic Guide

A. I. Zhamoida

All-Russian Institute of Geology, Srednii pr. 74, St. Petersburg, 199026 Russia

Received September 28, 1994

Abstract—The second, modified and essentially supplemented edition of the *International Stratigraphic Guide*, which was published in 1994, is discussed with consideration of its peculiar features and differences from the first edition published in 1976, and also from the Russian stratigraphic code of 1992. Three essential features differentiate the second edition of the guide from the first one: (1) chapters dealing with stratigraphic unconformity-bounded and magnetostratigraphic units were first introduced; (2) unlayered intrusive and metamorphic geological bodies were included into lithostratigraphic units; and (3) a glossary of stratigraphic terms was added. The *Guide*, which resulted from the fruitful cooperation of the World geological community, is appraised at its true worth.

Key words: *stratigraphic guide, stratigraphic units, lithostratigraphic, biostratigraphic, and chronostratigraphic units.*

The year 1976 was marked by an event that was important not only for international stratigraphy, but to some extent for geological science in general. The long standing efforts of the International Subcommission on the Stratigraphic Classification (ISSC) resulted in the publication of the first *International Stratigraphic Guide* (1976)[1] with Prof. H. Hedberg, the Chairperson of the Subcommission, as its editor. Despite its informal character (and, probably, because of this) Guide-76 played an important role for furthering a mutual understanding between geologists from different countries in respect to stratigraphic classification, terminology, and nomenclature, and also to the application of certain procedures in geological practice.

Guide-76 was translated into several languages, Russian included (*Mezhdunarodnyi* ..., 1978), and served as the basis for the elaboration of many national stratigraphic codes (Kovalevskii, 1984, 1986).

Also in 1976, Hedberg retired, and Prof. A. Salvador was elected to chair the above-mentioned subcommission. Salvador's suggestion to continue the efforts in adding and specifying the requirements of the guide was unanimously supported by subcommision members. In 1992, these efforts were crowned by the preparation of the second edition of the revised and supplemented International Stratigraphic Guide, which was published in 1994. Note that the first Russian stratigraphic code (*Stratigraficheskii* ..., 1977, 1979) was published one year after the first edition of the International Stratigraphic Guide, whereas the second, supplemented edition of the national code was published two years before the publication of the international guide.

[1] Further, it is designated as Guide-76 and its second, supplemented edition, as Guide-94.

The first edition of Guide-76 translated to Russian was discussed in a series of special publications (Menner, 1978; Zhamoida and Moiseeva, 1980; Zhamoida, 1984; and others), therefore, in the present paper, I will consider the differences between the first and second editions of the guide. This seems reasonable, because the concept of both editions is the same.

I will start with the peculiarities of the Guide-94 elaboration. Salvador and the subcommission members decided to maintain the informal character of the guide. Salvador proposed to prepare and include new chapters dealing with the unconformity-bounded and magnetostratigraphic units, the glossary of stratigraphic terms (with their translation to various languages), and an additional bibliography. Questions on including the chapters dealing with the seismostratigraphy, oceanic stratigraphy, soil stratigraphy, and igneous and metamorphic rock units were put forward for discussion (*ISSC Circular* no. 54, 1976).

When preparing the updated guide, Salvador made a tremendous effort. Usually, the distribution of a questionnaire regarding a particular chapter or topic was his first step. Then, summarizing all the answers obtained, he prepared the first draft version of the new or revised chapter. After obtaining comments and suggestions, the second version of the chapter was prepared and published, and so on up to the final version. Questionnaires, answers, comments and chapter drafts formed the basis of subcommission circulars. The circular number itself (from no. 54 in 1976 to no. 86 in 1993) proves the high activity of members of the subcommission and moreover, of its chairperson.

Most of the subcommission members made a decision not to include the chapters dealing with the seis-

mostratigraphy, cyclic-event stratigraphy, soil and ocean stratigraphy, and Precambrian and Quaternary stratigraphy. Suggestions on including into it the chapter on magnetostratigraphy have also provoked no objections. Intense discussions of questions concerning the unconformity-bounded units and also igneous and metamorphic rocks were undertaken. My attempts to show the nonstratigraphic nature of these units led only to a few amendments and reservations introduced by Salvador into pertinent chapters of the guide. These and my other suggestions will be discussed below.

In the preface, Salvador emphasized the importance of Guide-76 in the successful development of international stratigraphy, highly credited to Prof. Hadberg for his leading role as a chairperson of the subcommission, coauthor, and editor of the first edition, marked most important contributions to the second edition, and mentioned the *North American Stratigraphic Code* and *Field Geologist's Guide to Lithostratigraphic Nomenclature in Australia*, which were used when elaborating Guide-94. Two diagrams showing the dynamics of publications dealing with stratigraphic classification and terminology, and also that of the publication of national and regional codes since 1930 to 1990 were also given in the preface.

Salvador also considered it necessary to cite the complete text of Hedberg's preface to Guide-76 to emphasize the succession of both editions.

The structure of Guide-94 and titles of chapters and most sections remained unchanged. Chapter I (Introduction) is supplemented only by new information on the number of subcommission members, representing about 75 national and international stratigraphic organizations. The main sources used in the course of preparation of new chapters were also cited. At the same time, the section on voting for the publication of Guide-94 along with the Addendum to Guide-76 listing the ISSC members and showing the voting results were excluded from it.

The purposes of the publication set forth are the same as in the first edition: "to promote international agreement on principles of stratigraphic classification and to develop an internationally acceptable stratigraphic terminology and rules of stratigraphic procedure, all in the interest of improved international communication" (*International* ..., 1976, p. 1; 1994, p. 2). It was emphasized that the Guide should be considered as a recommended approach rather than a "code", and that the standards should not be legislated to ensure progress in investigations. In those cases which are not foreseen by the guide, scientists are recommended to follow common sense.

As in the first edition, the principles of stratigraphic classification (Chapter 2) were reduced to a substantiation of several equally significant categories of stratigraphic subdivisions defined by different properties of rocks. It is stressed that units of different categories commonly do not coincide. Still, in the concluding remarks, it is said that the characteristics of all units should supplement each other.

As before, lithostratigraphic, biostratigraphic, and chronostratigraphic units are considered to represent the best known and widely used subdivisions. A pertinent paragraph of the first edition of Guide-76 mentioned not categories of units, but elements of stratigraphy: lithostratigraphy, biostratigraphy, and chronostratigraphy.

The main terminological innovation in this and other chapters is that the terms *rock strata* or *stratified rocks* were substituted with the term *rock bodies* in definitions of all stratigraphic units. This substitution was necessary, because Guide-94 was supplemented by chapters dealing with the unconformity-bounded units and intrusive and metamorphic rock bodies. The term *body strata* was preserved only in the definition of biostratigraphic units.

Those categories, to which separate chapters are dedicated, were recognized to represent the formal ones, while other units used in stratigraphy (mineralogical, environmental, seismic, and based on stable isotopes) were considered to be so far informal.

The table presents the terms designating main stratigraphic units of different rank adopted in Guide-94.

Chapter 3 (Definitions and Procedures) begins, as in the first edition, with a definition of stratigraphy, which, however, was broadened to include into subjects of investigation *all* rock bodies of the earth's crust as *distinctive* and mappable units. Also, the requirement to study the unit's form and to interpret them in terms of environment and mode of origin was excluded from the definition. In fact, the exact definition of stratigraphy was not given. Instead, the thesis that all classes of rocks fall within the general scope of stratigraphy is twice repeated.[2]

According to Guide-94, "Stratigraphic procedures include the description, classification, naming, and correlation of these units for the purpose of establishing their relationship in space and their succession in time" (*International* ..., 1994, p. 13). Definitions of all other terms remained the same as before—only small amendments were introduced into some of them. For instance, the application of informal terms was broadened to use them for aquifers, oil and gas reservoirs, coal beds, quarry layers, and seismic horizons; as in the *North American Stratigraphic Code*, the terms *lithocorrelation* and *biocorrelation* were introduced in addition to the term *chronocorrelation*. Also, the definition of the term *stratum* was simplified and restricted only by its lithological properties. The definition of the *zone* also lacks an indication of its insignificant stratigraphic volume.

The second part of Chapter 3 dedicated to the recognition, revision, and description of stratigraphic units remained ideologically the same as before, although its

[2] This problem was intensely debated in Russia (Zhamoida, 1984).

form considerably changed and became more logical: the numerous paragraphs were united into four sections; special requirements for the names and introduction of stratigraphic units are discussed separately (as in the Russian code); and some wordings were specified. The recommendation to preserve traditional and widely recognized names of stratigraphic units was also added. At the same time, the hardly feasible requirement to name the stratigraphic units according to the spelling adopted in the country where the stratotype is located was ommited from the guide.

Chapter 4, dedicated to stratotypes, offers a new definition of the boundary-stratotype. I was successful in convincing Salvador that the specific point in a specified sequence cannot serve as a boundary-stratotype and standard for its definition (*ISSC Circular* no. 76, 1989). As a result, "the specified sequence of rock strata in which a specific point is selected that serves as the standard for definition and recognition of a stratigraphic boundary" is adopted to represent the boundary-stratotype that is illustrated by the corresponding figure (*International* ..., 1994, p. 26, Fig. 2). Ergo, the wording from the Russian code was accepted (*Stratigraficheskii* ..., 1977, 1992).

One of my objections to the inclusion into the scope of stratigraphy of unconformity-bounded units and nonlayered igneous and metamorphic rock bodies was based on the natural statement on the impossibility to select their stratotype. Salvador found a solution to this situation by broadening the notion on *type locality*. This term is now not restricted only to the geographic place where a layered unit stratotype or its boundary-stratotype are located. "In the case of stratigraphic units composed of nonlayered igneous or metamorphic rock bodies, the type locality is the specific geographic locality where the unit was originally defined and named, the standard of its definition" (*International* ..., 1994, p. 27). I do not think that the ambivalent meaning of this term is the best choice to resolve this dilemma. In this case, the substitution of the notion of the *stratotype*, i.e., the *sequence* with that of the *type locality* confirms, in my view, the nonstratigraphic nature of the above-mentioned units.

The new requirements for stratotypes suggest them to be supplemented with a geologic map of the area including the stratotype and assurance of preservation of the latter. As for chronostratigraphic (general stratigraphic) units, it is recommended to select the stratotype of their lower boundary.

The following chapters contain the description of stratigraphic units of five categories.

Lithostratigraphic units (Chapter 5) are defined and characterized on the basis of their lithologic properties and stratigraphic position. Introduction of the latter criterion draws together this definition with the definition of the *straton* in the Russian Stratigraphic Code (*Stratigraficheskii* ..., 1977, 1992). It was specially stressed that the considered units are the basic units for geologic mapping. The definition of the *formation*, as a principal lithostratigraphic unit, was supplemented with the requirement adopted from the *North American Stratigraphic Code* (1983): "no formation is considered justifiable and useful that cannot be lineated at the scale of geologic mapping practiced in the region where the formation is proposed." In the first edition, this thesis was suggested as a desirable rather than an obligatory one.

The section dealing with the naming of lithostratigraphic units was broadened to include the explanation of the lithologic part of names and also names of nonlayered rock bodies of intrusive, metamorphic, or uncertain origin. As in Guide-76, it is recommended that the name of a lithostratigraphic unit should be formed from the name of an appropriate local geographic feature combined with a lithologic term indicating the dominant rock type (granite, gneiss, schist, etc.); in the case of a combination of different rocks, the term *complex* is used. Such terms as *melange* and *ophiolite* may also be applied. On the other hand, the use of the term *suite* for nonlayered rocks is inadvisable because in the former Soviet Union and in some countries of Eastern Europe, this term has another meaning. This was a response to my comment (*ISSC Circular* no. 69, 1985).

It was admitted that the stratigraphic position of these bodies often cannot be defined. Therefore, geochronometric age estimates based on the isotopic method and also relative age with reference to layered and/or other nonlayered rocks should be used.

The new Chapter 6, dealing with unconformity-bounded units, was debated in the subcommision from 1981. However, the discussion on the stratigraphic status of these units began as far back as the 1940s (Sloss *et al.*, 1949). Wheeler (1959) proposed to include them into the American code. Chang (1975) published a special paper where he suggested the terms *synthem* and *interthem*. They were included into the *North American Stratigraphic Code* (1983) under the name "allostratigraphic units" (Kovalevskii, 1986).

After debates on the topics suggested to the sucommission members by its chairperson, the draft versions of wordings and the chapter itself were published in four successive issues of the Circular. In my responses, I have noted that these units are of tectonic rather than stratigraphic nature, and that in the Russian stratigraphic code, they are absent. Even now, I cannot refer them to classical stratigraphy, though they evidently may fall within the scope of global stratigraphy in my meaning (Zhamoida, 1994).

The long-standing discussion resulted in the following definition of the unconformity-bounded units. These are bodies of rocks bounded above and below by significant and recognizable discontinuities in the stratigraphic succession (angular unconformities, disconformities), preferably of a regional or an interregional extent. They may include other kinds of stratigraphic units (litho-, bio-, chrono-, magnetostrati-

Summary of categories and unit-terms in stratigraphic classification

Stratigraphic categories	Principal stratigraphic unit-terms	Equivalent Geochronologic Units
Lithostratigraphic	Group Formation Member Bed(s), Flow(s)	
Unconformity-bounded	Synthem	
Biostratigraphic	Biozones: Range zones Interval zones Lineage zones Assamblage zones Abundance zones Other kinds of biozones	
Other (informal) stratigraphic categories (mineralogic, stable isotope, envirinmental seismic, etc.)	Zone (with appropriate prefix or adjective)	
Chronostratigraphic	Eonothem Erathem System Series Stage Substage (Chronozone)	Eon Era Period Epoch Age Subage (or Age) (Chron)

Note: The table is cited after (*International* ..., 1994).

graphic, and others) from small to large both in vertical and lateral succession. The diagnostic criteria used to recognize these stratigraphic units are their two designating boundary unconformities. However, the description of composition, thickness, fossils, geomorphology, and age is necessary when recognizing the considered units.

The basic unconformity-bounded unit is the *synthem*, which, when necessary may be subdivided into *subsynthems*. Two or more synthems may be combined into *supersynthems*. The synthem ranking can be based on the importance of bounding discontinuities with regard to the degree of angular unconformity, the time span of the stratigraphic hiatus, and geographic extension of the discontinuity. Stratotypes (though, from my point of view, the use of this term is hardly justified in this case) of the lower and upper bounding unconformities may be selected in different sequences (I would say, localities or areas). The names of synthems are formed from the name of the appropriate geographic feature.

Two notes or rather comments draw particular attention. First, it is stressed that unconformity-bounded units should be established only in those cases when other categories of stratigraphic units cannot be established (evidently, in the given scope). Second, the considered units may be regarded as equivalent to sedimentary cycles or various tectonically controlled units (cycles, stages, and so on); but, if the recognition of the latter units requires a genetic or causal interpretation, synthems are established as objective noninterpretative stratigraphic units (according to the guide). Usually, they are extensively used in stable cratonic areas and orogenic belts.

It has also been noted that these units were the basis for establishing many previously defined stratigraphic units, e.g., many systems (*sic* in the Guide) in their original meaning.

Chapter 7, dedicated to biostratigraphic units, was twice revised by Salvador, though its final version is structurally identical to that of Guide-76. Simultaneously, it was somewhat reduced and presents concise and clearer characteristics of units and different terminology concerning some zones.

Biostratigraphy is defined to be the element of stratigraphy dealing with the description of fossils in the stratigraphic succession and organization of strata into units on the basis of the contained fossil taxa.

Biostratigraphic units are bodies of rock strata that are defined and characterized on the basis of the contained fossils.

As in Guide-76, the following biostratigraphic zones are defined: *range-zone* (with two varieties: *taxon-range zone* and *concurrent-range zone*), *interval zone*, *assemblage zone*, and *acme zone* (renamed to the *abundance zone*). The *lineage zone* was separated from the range zone. The *Oppel zone*, which is consid-

ered to be a kind of assemblage concurrent zone, was excluded from Guide-94. Different kinds of zones are independent.

As before, the term *biozone* is used as a short alternative term for the *biostratigraphic zone*. Instead of the terms *interzone* and *infrazone* designating stratigraphic intervals with no fossils, the single term *barren interval* was proposed. Also included is the term *zonula* for the fine subdivision of the zone or subzone.

The requirement of complete (lateral or vertical) distribution of the taxon for the corresponding zone was substituted by a recommendation to indicate the known stratigraphic and geographic ranges of taxon occurrence. Only two specified taxa are recommended to be indicated for the concurrent-range zone.

When describing the drill hole section, the *last-occurrence zone* or *highest-occurrence zone*, as a variety of the interval zone may be defined.

According to the editor, the *phylogenetic zone*, which was termed as the *lineage zone*, should be considered to represent the chronozonal unit. It should be noted that the definition of this zone, as well as further comments, are somewhat ambiguous. For instance, the exempt notion on the trend in the phylogenetic lineage from the zone definition results in the loss of its essence, because the wording "certain localization of fossil taxa in the stratigraphic record and their objective identification" is applicable to zones of any kind. The evolutionary, morphogenetic, and phylogenetic zones are considered to be synonyms of the lineage zone, but not phylozone in Van Hinte's (1969) meaning.

As in Guide-76, the new edition lists the synonyms of biohorizon (level, boundary, surface, marker, datum plane, and others). They were supplemented with two abbreviated terms for the levels of the first and last occurrence of taxa: FAD = first appearance datum and LAD = last appearance datum.

The requirement for selecting stratotypes of the biostratigraphic units became less strict, but the designation of one or more reference sections that contain diagnostic taxa of the unit is recommended.

When naming biostratigraphic units, the use of a specific epithet alone, if the genus name is not indicated before is inadvisable. Code (letter or number) designation should be used with prudence and considered informal.

Magnetostratigraphic units (Chapter 8) were first included into Guide-94, though discussion on this topic was put forth by Hedberg as far back as 1972. He was the first to propose the first version of the chapter (*ISSC Circular* no. 55, 1977). Its final text was prepared by the International Subcommission on Stratigraphic Classification and Subcommission on a Magnetic Polarity Time Scale.

In the first section of the chapter, the nature of magnetostratigraphic polarity units and two ways of their application are briefly considered. The application includes the evaluation of the remnant magnetization of rocks as in usual stratigraphic work and identification of marine linear magnetic anomalies that provides a more complete record of reversals of the earth's magnetic field during the last 150 million years and may be used when reconstructing the geological history of the oceanic areas. Further in this section, the remnant magnetization of rocks is discussed.

Magnetostratigraphy is defined to represent the element of stratigraphy that deals with the magnetic characteristics of rock units.

Magnetostratigraphic units (Magnetozones) are bodies of rocks unified by similar magnetic characteristics (not only magnetic polarity), which allow them to be differentiated from adjacent rock bodies. *Magnetostratigraphic polarity units* are bodies of rocks characterized by magnetic polarity that allow them to be differentiated from adjacent rock bodies.

Magnetostratigraphic polarity-reversal horizon represents the surface or very thin transition interval of rock strata (in practice, about 1 m thick) corresponding to the inversion of magnetic polarity and marking the boundary of a magnetic polarity unit.

The basic unit in the classification of magnetostratigraphic polarity units is the *magnetostratigraphic polarity zone*, or simply, a *polarity zone*. Polarity zones may be subdivided into *polarity subzones* or *microzones* and combined into *polarity superzones* or *megazones*. In Guide-94, recommended units are not correlated with certain intervals of geological time, or with units of the general stratigraphic scale as was done in the Russian stratigraphic code (*Stratigraficheskii ...*, 1992). Magnetostratigraphic polarity zones may show a single polarity of magnetization, an intricate alternation of intervals with normal and reversed polarities, or the predominance of one of them.

The procedure of discriminating magnetostratigraphic units includes a special description of reference and stratotype sections using isotope datings and paleontological data. The formal name of the unit should be formed from the geographic name combined with the appropriate term of its rank and indication of the polarity sign, for instance, Gauss Normal Polarity Zone, or Jaramillo Reversed Polarity Subzone. Small units may be designated by numbers and letters, and should be considered informal. The use of the terms *epoch*, *event*, and *interval* is not recommended; the terms *chron*, *polarity chron*, or *chronozone* are suggested instead.

In terms of its content, the Chapter 9 dealing with chronostratigraphic units is almost identical to the corresponding chapter in Guide-76. The principal difference is that the chronozone was excluded from the formal hierarchical scale, which terminates with the substage, whereas the stage is recognized as a basic working unit of chronostratigraphy, which allows global correlation. Unlike the previous recommendation to distinguish the stages in the most complete sections and favorable facies, Guide-94 suggests that the stage be

defined by its stratotype of the lower boundary using the Global boundary stratotype section and point or GSSP (*Stratigraficheskii* ..., 1992, Addendum 2) recommended by the International Commission on Stratigraphy.

Chronostratigraphy is defined to be the element of stratigraphy that deals with the relative time relations and ages of rock bodies. Like in Guide-76, two its specific objectives are indicated as follows: (1) to determine time relations of local and regional units; and (2) to establish the Standard Chronostratigraphic Scale with an arranged hierarchy of units. Simultaneously, the definition of the term *chronostratigraphic unit* essentially changed.

In the present definition, chronostratigraphic unit is "a body of rocks that includes all rocks formed during a specific interval of geologic time and only those rocks formed during that time span. Chronostratigraphic units are bounded by isochronous horizons" (*International* ..., 1994, p. 78). The *chronozone* is regarded as a nonhierarchical, but formal chronostratigraphic unit defined within the time span of any previously established unit: formation, member, biozone, polarity zone, and so on. It may correspond to any time interval.

Whereas the section concerning the units of the Quaternary System was preserved in its previous content and only its time span (1.6–1.64 Ma) was added, the section dedicated to the Precambrian was not only broadened, but essentially revised. Guide-76 declared a single approach to the subdivision of the Precambrian and Phanerozoic into the major chronostratigraphic units, though the ways of time correlation could be different. The same approach was recommended by the Russian stratigraphic code (*Stratigraficheskii* ..., 1977, 1992). In Guide-94, the Archean and Proterozoic (with the boundary between them at 2500 Ma) are regarded as not chronostratigraphic, but geochronologic units, i.e., units of geologic time disconnected with the succession of rocks, to which they may be referred. The Precambrian rocks are subdivided into arbitrary geochronologic units of different significance. The editor was forced to accept different approaches to the subdivision of the Phanerozoic and Precambrian in the general global scale, because igneous and metamorphic rocks were included into the scope of stratigraphy.

A special section was dedicated to the Standard Global Chronostratigraphic (Geochronologic) Scale. In Guide-94, this scale was supplemented by a column showing the series of the Phanerozoic System and ages of boundaries between systems according to Palmer (1983), Snelling (1987), and Harland *et al.* (1990). The column showing the duration of periods was eliminated from the scale. The Precambrian was subdivided into the Archean and Proterozoic, which are now classified as *eons*.[3] Nine of the ten comments which were dedicated in Guide-76 to a historical review of the recognition and names of the standard scale units, are also absent from Guide-94. In my view, these useful comments, on the contrary, could be supplemented by additional ones. At the same time, in a footnote, it is indicated that the Tertiary System is subdivided into the Paleogene and Neogene Subsystems.

I have already mentioned (Zhamoida, 1980; Zhamoida and Moiseeva, 1984) that the structure of the Russian stratigraphic code and some other national codes provoked, to some extent, Hedberg to include the section "Regional stratigraphic scales" into the guide. In Guide-94, this section was supplemented with an indication that local and regional chronostratigraphic units should follow the same rules as for units of the Standard Global Chronostratigraphic Scale.

The procedure for establishing chronostratigraphic units is, in fact, restricted by the requirement to select the boundary stratotypes; in this case, it is preferable to select the lower boundary that automatically appears to represent the upper boundary of the underlying unit. In addition to general requirements for the stratotype selection (Chapter 4-C), some specific requirements for the boundary-stratotype of chronostratigraphic units are indicated: (1) continuity of stratigraphic record in marine sections without major vertical changes in lithofacies and biofacies (for the local chronostratigraphic units, nonmarine sections are also suitable); (2) presence of diverse, abundant, and well-preserved fossil assemblages; (3) the lowest degree of structural deformation and metamorphism; and (4) where possible, the presence of good marker horizons or other features favorable for time correlation. The importance of the thorough study of the selected section and publication of the results was emphasized. It is also recommended that the selection of the boundary-stratotypes of chronostratigraphic units should take into account the historical priority and approximate the traditional boundaries.

It has been noted that the Internatonal Commission on Stratigraphy is responsible for coordinating the selection and approval of Global boundary stratotype section and points for the units of the Standard Global Chronostratigraphic Scale.

Chapter 10 deals with the relation between different kinds of stratigraphic units, including those that were added to the guide, i.e., the unconformity-bounded and magnetostratigaraphic units.

Both of the last categories are the objective units, i.e., they may be established when diagnostic properties, on which they are based, are present in the rocks.

The boundaries of the unconformity-bounded units are always diachronous to a lesser or greater extent, but the units themselves are of chronostratigraphic significance, and sometimes may correspond to some unit of this category. The time span of these units may vary from the age (substage) to more than an entire geological period.

[3] In the Russian stratigraphic code (*Stratigraficheskii* ..., 1992), the Archean and Proterozoic were recommended to be considered as the acrothems (acrons).

Magnetostratigraphic polarity units are essentially similar to lithostratigraphic and biostratigraphic units, but differ from them in the potentially worldwide extent. This makes them similar to chronostratigraphic units because polarity reversals occur through a time span of no more than 5000 years. Magnetic-polarity-reversal horizons are essentially isochronous and, thus, they may serve as the basic characteristics of chronostratigraphic units. However, because of relatively limited individuality of magnetic-polarity zones and horizons, their position in the section may be established only by taking account of paleontological and isotopic age constraints.

Thus, like in Guide-76, the idea that all kinds of independent stratigraphic units are closely interrelated is persistently pursued through the second edition. This idea was formulated by Hedberg, not without influence of European geologists, Soviet scientists included.

A glossary of stratigraphic terms was first included into Guide-94, though its compilation and translation to several languages was planned during the work on the Guide-76 preparation. The glossary contains 376 terms, synonyms included. These terms are given in English, and many terms from other non-English national codes are not included into the glossary. The Russian geological terminology is represented by a single term *suite* as one of four synonyms of this term. Twenty nine terms have two–three meanings. The International Subcommission on Stratigraphic Classification plans to prepare a multilingual glossary of stratigraphic terms in the future.

Guide-94 concludes, like the first edition, with a list of national to regional codes and references on stratigraphic classification, terminology, and procedures.

Sixty three codes and like documents (five of them are translations including the Russian version published in 1979) are cited in the list. Most of the 26 countries whose codes are cited in the list are represented by a single publication each. Several countries are represented by more than one publication: seven for Australia and the USSR (the list starts with the booklet *Stratigraficheskie i geokhronologicheskie edinitsy* published in 1954); six for the Great Britain; four for the USA and China; three for South Africa; and two for Norway, Bulgaria, Germany, Argentina, and Indonesia. In his preface, Salvador gave an interesting diagram showing the dynamics of the publication of codes. The most fruitful five years appeared to be between 1965–1970, when 13 codes were published. After 1986, only five codes were issued, including the Russian code of 1992 and its draft version of 1988.

The reference list cites 1153 publications, 186 (or 1/6) of which are works by Soviet scientists including the earliest paper by Krishtofovich (1939) on the new system of regional stratigraphy. In Guide-76, the Soviet scientists were represented by 169 (or 1/8) of total 1381 references. It is interesting that the general diagram also given in the preface showing the dynamics of publications on stratigraphic classification, terminology, and procedures is very similar to the above-mentioned one, i.e., it proves the increasing number of publications since 1950s, with their maximum number in 1970–1979, and sharp decrease after 1990.

I do not think that it is necessary to speak much about the great importance of the considered fundamental work for international stratigraphy in particular and for geology in general. This was specially emphasized by Prof. J. Remane, the President of the International Commission on Stratigraphy in his foreword to Guide-94.

I wish to finish this review with words of gratitude to Prof. A. Salvador, coauthor and editor of Guide-94, for his long standing selfless efforts that were crowned with such a great success.

Reviewer B.S. Sokolov

REFERENCES

Chang, K.H., Unconformity-Bounded Stratigraphic Units, *Bull. Geol. Soc. Am.*, 1975, vol. 86, no. 11, pp. 1544–1552.

Harland, W.B., Cox, A.V., Llewellin, P.G., Pickton, C.A.G., Smith, A.G., and Walters, R., *A Geologic Time Scale*, Cambridge: Cambridge Univ., 1982. Translated under the title *Shkala geologicheskogo vremeni*, Moscow: Mir, 1985.

International Stratigraphic Guide, Hedberg, H.D., Ed., New York: Wiley, 1976.

International Stratigraphic Guide, Salvador, A., Ed., Geol. Soc. Amer., 1994, 2nd ed.

ISSC (International Subcommission on Stratigraphic Classification). Circular no. 54, 1976.

ISSC. Circular no. 55, 1977.

ISSC. Circular no. 69, 1985.

ISSC. Circular no. 76, 1989.

Kovalevskii, O.P., Foreign Stratigraphic Codes, in *Obshchaya i regional'naya geologiya, geologicheskoe kartirovanie* (General and Regional Geology, Geological Mapping), Moscow: Vses. Inst. Ekonomiki Mineral'nogo Syr'ya, 1984, pp. 1–25.

Kovalevskii, O.P., New North American Stratigraphic Code, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1986, no. 4, pp. 130–135.

Menner, V.V., On the History of the International Stratigraphic Guide, *Izv. Akad. Nauk, Ser. Geol.*, 1978, no. 7, pp. 78–86.

North Americam Stratigraphic Code, *Bull. Am. Assoc. Petrol. Geol.*, 1983, vol. 67, no. 5, pp. 841–875.

Palmer, A.R., The Decade of North American Geology 1983. Geologic Time Scale, *Geology*, 1983, vol. 11, no. 9, pp. 503–504.

Sloss, L.L., Krumbein, W.C., and Dapples, E.C., Integrated Facies Analysis, *Sedimentary Facies in Geologic History*, Longwell, C.R., Ed., Mem. Geol. Soc. Amer., 1949, vol. 39, pp. 91–123.

Snelling, N., Measurement of Geological Time and the Geological Time Scale, *Modern Geology*, 1987, vol. 11, pp. 365–374.

Stratigraficheskii kodeks SSSR (Stratigraphic Code of the USSR), Leningrad: Vses. Geol. Inst., 1977.

Stratigraficheskii kodeks (Stratigraphic Code), St. Petersburg: Mezhved. Stratigr. Komitet, 1992, 2nd ed., suppl.

Van Hinte, J.E., The Nature of Biostratigraphic Zones, *Proc. 1st Int. Conf. on Planktonic Microfossils*, Bronnimann, P. and Benz, H.H., Eds., 1969, vol. 2, pp. 267–272.

Wheeler, H.E., Unconformity-Bounded Units in Stratigraphy, *Bull. Am. Assoc. Petrol. Geol.*, 1959, vol. 43, no. 8, pp. 1975–1977.

Zhamoida, A.I., Comparing the Soviet Stratigraphic Code with the International Guide, *Episodes*, 1984, vol. 7, no. 1, pp. 9–11.

Zhamoida, A.I., Essential Features and Relations between Basic Stratigraphic Units, *Tr. Mezhved. Stratigr. Kometeta*, Leningrad: Nedra, 1980, vol. 7, pp. 32–63.

Zhamoida, A.I., Straigraphic Space or the World of Stratigraphy, *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 2, pp. 3–11.

Zhamoida, A.I. and Moiseeva, A.I., International Stratigraphic Guide and Stratigraphic Code of the USSR—Similarity and Differences, *Sov. Geol.*, 1980, no. 1, pp. 55–65.

Stratigraphy and Geological Correlation, Vol. 4, No. 5, 1996, pp. 514–516. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 5, 1996, pp. 102–104.
Original Russian Text Copyright © 1996 by Bidashko, Petrenko.
English Translation Copyright © 1996 by МАИК Наука/Interperiodica Publishing (Russia).

BRIEF COMMUNICATIONS

Early Holocene Fossil Insects and Natural Environments in the Ural River Lower Course

F. G. Bidashko* and Yu. V. Petrenko**

** Ural Antiplague Station, ul. Chapaeva 36/1, Ural'sk, 417001 Kazakhstan*

*** Ural Pedagogical Institute, prosp. Lenina 162, Ural'sk, 417000 Kazakhstan*

Key words: *fossil insects, lower Holocene, paleoecology, Ural River.*

The work is a continuation of studies begun earlier (Bidashko and Proskurin, 1984, 1987; Bidashko, 1987, 1988).

The outcrop discussed is located on the right bank of the Ural River near the Saraichik Settlement of the Gur'ev district; it was described by many researchers (Pravoslavlev, 1913; Zhukov, 1945; Fedorov, 1957).

According to our observations, layers represented by ash green clays with fossil insects and plant remains (reed macroremains prevail) fill in a depression of the oxbow lake type, which is cut across by the Ural River bank. Chitin-bearing layers grade laterally into a floodplain alluvium 1.5–2 m thick with gypsum crystals and inclusions of coalified plant remains. Down the section, they are replaced below a hiatus by a horizon of ochreous and yellow sands alternating with light-brown clays up to 1 m thick. The horizon base is covered with a talus. From sands of the lower horizon P.V. Fedorov extracted and determined molluscs *Didacna ebersini* Fed., *Monodacna caspia* Eichw., *Adacna plicata* Eichw., and *Dreissena polymorpha* Pall., which he assigned to the lower Khvalynian complex.

Sample UPI-435 with insect and plant remains was dated at 9780 ± 65 years in the Radiocarbon laboratory of the Ural Pedagogical Institute (Ural'sk).

The procedure of collecting, mounting and preparing the fossil insects for determination was described earlier (Bidashko, 1987). The material was determined at the Zoological Institute of the Russian Academy of Sciences (St. Petersburg) by means of comparing it with recent species and paleoentomological material collected from an area north of the Caspian Sea.

Data on the taxonomic analysis of the orictocoenosis are represented in Table 2.

A group of polyzonal fossils, the distribution area of which also includes the forest zone, comprises *Hygrous piceus, Hygrotus* cf. *versicolor* Schall., and *Coelostoma orbiculare* F.

Taxons occurring within the forest-steppe, steppe and desert zones include *Cybister lateralimarginalis, Aulonogyrus concinnus, Gonocephalum* sp.

The distribution of *Belopus* sp. and *Mesagroicus* sp. is more strictly confined to the northern part of steppes, while darkling beetles *Belopus* are common in landscapes up to and including dry steppes.

It is interesting to note that *Anemia dentipes* Ball. and *Megamecus variegatus* Gebl. are mainly distributed throughout southern Kazakhstan and Central Asia, and to the northwest their habitat area is confined to the southeastern European part of the former USSR.

All insects found and determined inhabit the studied region at present.

The method of superposition of distribution areas showed that in the early Holocene, the climate and general conditions of the studied region were similar to those in recent time. Calculated parameters of the paleoclimate are given in Table 1, and the zonal geographic distribution is illustrated in the figure.

Carabidae dominate (73.3%) in the studied orictocoenosis. Chrysomelidae prevail (26.4%) at the family level due to abundant *Donacia*. Hydrophilidae (16.2%) and Gyrinidae (15.9%) rank next, remains of *Hydrous piceus* L. dominate (10.5%) among water scavenger beetles, whereas *Aulonogyrus concinnus* Klug. prevail (7.5%) among whirligig beetles. Ground beetles rank third, represented by riverside forms (14.5%). Curculionidae (11.4%) represented mainly by sclerites of *Bagous* sp. (7.0%) occupy the fourth place. *Colymbetes* sp. and *Cybister lateralimarginalis* Deg. prevail among

Table 1. Average climatic parameters inferred from paleoentomological data

Climatic parameters				
1	2	3	4	5
−10 ... −11°C	24–25°C	150–175	1000	0.2

Note: (1) Average monthly temperature in January; (2) average monthly temperature in July; (3) average annual precipitation, mm; (4) average annual potential evaporation, mm; (5) index of humidification (ratio between annual precipitation and annual potential evaporation).

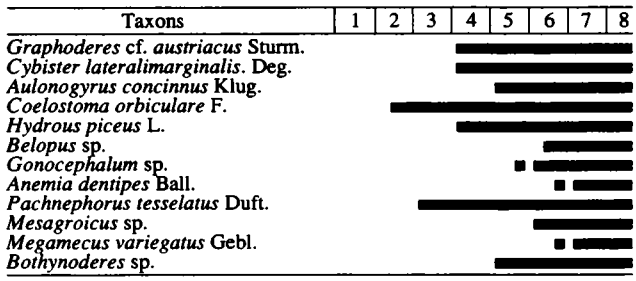
Table 2. Orictocoenosos of insects from Saraichik locality (Sr-1)

Taxons	Fossils	Taxons	Fossils
Coleoptera		Elateridae indet.	1 Mth
Carabidae		Buprestidae	
Dischirius sp.	1 El; 3 AnD	Buprestidae indet.	1 El
Bembidion sp.	9 El; 1 AnD; 4 H	Anthicidae	
Chlaenius (*Chlaenites*) sp.	1 H	Anthicidae indet.	1 El; 6 AnD
Pterostichus sp.	1 AnD	Tenebrionidae	
Agonum sp.	1 AnD	*Belolpus* sp.	2 H
Carabidae indet.	5 H; 3 Mth; 1 Msth + Mth; 3 St	*Gonocephalum* sp.	1 H
Dytiscidae		*Anemia dentipes* Ball.	1 H
Hygrotus cf. *versicolor* Schall.	1 El	Chrysomelidae	
Hygrotus sp.	1 El	*Donacia* sp.	19 El; 13 H; 23 AnD; 4 Mth; 1 St
Colymbetes sp.	5 El	*Pachnephorus tesselatus* Duft.	1 El
Graphoderes cf. *austriacus* Sturm.	1 AnD	Alticinae indet.	1 AnD
Cybister lateralimarginalis Deg.	5 El	Curculionidae	
Dytiscidae indet.	3 Mth	*Mesagroicus* sp.	1 El
Gyrinidae		*? Megamecus variegatus* Gebl.	1 H
Aulonogyrus concinnus Klug.	16 El; 1 AnD	*Bothynoderes* sp.	2 H
Gyrinus sp.	7 El; 1 AnD	? *Xanthochellus eversmanni* Fahr.	1 El
Gyrinidae indet.	11 H	*Lixus* sp.	1 El
Hydrophilidae		*Ceuthorrhynchus* sp.	1 Abd
Berosus sp.	1 El	*Bagous* sp.	9 El; 2 AnD; 2 H; 1 Abd; 2 St
Enochrus sp.	7 El; 3 H	*Notaris* sp.	1 El
Coelostoma orbiculare F.	1 El	Curculionidae indet.	2 AnD
Hydrous piceus L.	5 El; 1 AnD; 5 H; 3 Mth 2 St; 3 Sen; 4 Ext; 2 X	Coleoptera indet.	20 El; 7 H; 7 AnD; 7 Mth; 2 Abd; 2 Msth + Mth; 2 St; 5 Man; 17 X
Histeridae		*Heteroptera*	
Histeridae indet.	1 El	Corixidae	
Staphylinidae		Corixidae indet.	1 AnD
Bledius ex gr. *spectabilis* Kr.	1 AnD	Heteroptera indet.	1 AnD; 1 H; 1 St; 1 Abd
Staphylinidae indet.	1 El; 3 H; 1 AnD; 1 In; 1 Abd	*Hymenoptera*	
Scarabeidae		Formicidae	
Aphodius sp.	1 El	Formicidae indet.	2 H
Dryopidae		*Insecta*	
Dryops sp.	1 El	Insecta indet.	4 H; 1 St; 50 X
Elateridae		Total of the studied fragments:	365

Note: El—elytron; AnD—anterodorsum; H—hethrus; In—intact insect; Abd—abdomenal part of an insect; Mth—metathorax; (Msth + Mth)—unified mesothorax and metathorax; St—sternals; Ext—extremity; Man—mandibles; Sen—sentellum; X—fragments of unverified morphology.

Dyctiscidae (7.0%). The rest of the five families are not abundant.

The peculiar composition of the orictocoenosis, in which aquatic and intrazonal forms dominate, can be explained by the screening effect of vegetation. It is likely that the oxbow lake was the burial place. Its banks were covered with reeds, which were separated from flat interfluve localities by a wide strip of mead-



Zonal geographical distribution of taxons as indicators of Sr-1 orictocoenosis.

(1) Tundra; (2) forest-tundra; (3) taiga; (4) broad-leaved forest zone; (5) forest-steppe; (6) steppe; (7) semi-desert; (8) desert.

ows. The flooding of reeds resulted in depletion of the taxonomic composition of riverside insects and restricted the access of forms from the interfluve flatland and meadow to the burial place.

Reviewers A.P. Rasnitsyn and A.G. Ponomarenko

REFERENCES

Bidashko, F.G., Comprehensive Procedure of Collecting Fossil Insects with the Use of Kerosene Flotation, and Recommendations on the Preparation of Insects for Determinations, *Zool. Zh.*, 1987, vol. 66, no. 7, pp. 1086–1089.

Bidashko, F.G., Characteristics of Evironments in the Volga Lower Course Area during the Singilian Time by Paleoentomological Data, in *Voprosy geologii i sovremennoi geodinamiki Nizhnego Povolzh'ya* (Aspects of Geology and Recent Geodynamics of the Lower Volga Region), Saratov, 1988, pp. 75–82.

Bidashko, F.G. and Proskurin, K.P., Environments in the Ural River Lower Course during the Middle Pleistocene by Entomological and Botanical Data, *Paleontol. Zh.*, 1984, no. 2, pp. 82–88.

Bidashko, F.G. and Proskurin, K.P., Reconstruction of Environments in the Lower Volga Area for the Singilian Time (Middle Pleistocene) by Entomological and Carpological Data, *Paleontol. Zh.*, 1987, no. 4, pp. 69–75.

Fedorov, P.V., Stratigraphy of Quaternary Deposits and the Caspian Sea History, *Tr. Geol. Inst. Akad. Nauk SSSR*, 1957, no. 10.

Pravoslavlev, P.A., Caspian Sediments Along the Ural River, *Izv. Donsk. Politekhn. Inst.*, 1913, sect. 2, no. 2, pp. 565–624.

Zhukov, M.M., Pliocene and Quaternary History of the Northern Caspian Sea Depression, in *Problemy zapadnogo Kazakhstana* (Problems of Western Kazakhstan), Moscow: Akad. Nauk SSSR, 1945, vol. 2.

Stratigraphy and Geological Correlation, Vol. 4, No. 5, 1996, pp. 517–522. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 5, 1996, pp. 105–110.
Original Russian Text Copyright © 1996 by Dorofeeva, Prilutskii, Shkatova.
English Translation Copyright © 1996 by МАИК Наука/Interperiodica Publishing (Russia).

BRIEF COMMUNICATIONS

The Double Carbonate Thermometer as a Tool for Correlation and Stratigraphic Subdivision of the Quaternary Deposits

L. A. Dorofeeva, R. E. Prilutskii, and V. K. Shkatova

All-Russian Institute of Geology (VSEGEI), Srednii pr. 74, St. Petersburg, 199026 Russia

Received June 8, 1994; in final form, December 21, 1995

Keywords: *Correlation, Pleistocene, the Caspian Sea, biogenic carbonate, oxygen isotopic composition, paleotemperature, paleosalinity, paleoclimate.*

Recently, oxygen isotope deep-water climatostratigraphy has become the most developed and widely used method of Quaternary geology. It is based upon the correlation of climatic oscillations and the alternation of continental glaciations and interglaciations reflected by oxygen isotopic composition in calcium carbonate composing shells of oceanic microorganisms (δ_c) and sea water (δ_w). The cold epochs are marked by a higher content of heavy oxygen isotope ^{18}O in both the water and carbonate in contrast to the warm ones. The succession of climatic events is evident in the δ_c variations recorded in the Quaternary deposits. Nineteen oxygen isotope stages with substages lasting from several to dozens k.y. (Martinson *et al.*, 1987) were distinguished within the last period of 730 (780) k.y.

The subdivision and correlation of the Quaternary beds is based upon comparison of respective oxygen isotope curves reflecting climatic variations. The commonly used oxygen isotope method reveals only relative characteristics of environmental changes. Furthermore, the method can hardly be used if we have indications that oxygen isotope composition of water is not constant and close to that of the present ocean water (Epstein and Mayeda, 1953).

Joint use of the oxygen isotope and micropaleontologic methods is valuable in reconstructing variations of the surface water temperature in oceans during the Cenozoic (Nikolaev, 1986). This rather laborious approach is mainly used in studies on the oceanic deposits.

In order to obtain similar parameters for the inland basins, the authors suggest utilizing the double carbonate thermometer method, newly invented in VSEGEI, in which the same carbonate shell sample of a marine invertebrate is subjected to both mass spectrometric analysis on the oxygen isotope composition (Prilutskii *et al.*, 1986; *Fizicheskie ...*, 1988) and determination of the calcium and magnesium content by the means of atomic absorption (*Fizicheskie ...*, 1988). The method was tested by using calcite shells of Mesozoic–Cenozoic marine mollusks from the Barents, White, and Black seas, and the Sea of Azov. The errors of measurements were 0.6‰, 1.0°C and 10‰ for the oxygen isotope composition, and water temperature and salinity, correspondingly (Dorofeeva *et al.*, 1994).

To test the advantages of this method, we studied aragonite shells of bivalve mollusks of the *Didacna* Eichwald genus, which represent a group of index fossils from the Pleistocene deposits of the inland brackish-water Caspian Sea (the Lower Volga region). *Didacna* shells were sampled from the upper Khazarian deposits, which are dated by paleontological, thorium–uranium (Th/U), thermoluminiscence (TL) and paleomagnetic methods.

Geological and paleontological data show that the Pleistocene climatic optimum corresponds to the late Khazarian transgressive phase (Shkatova, 1979). The latter corresponds to the 5*e* substage (Martinson *et al.*, 1987) of the Riss–Wurm, Eemian, and Mikulino interglacials (130–117 ka). The respective regressive phase corresponds to the colder epoch of the substages 5*d–a* (117–74 ka) of the early Wurm, early Valdai, and early Visla glaciations in Northern and Central Europe. As a whole, the early Khazarian deposits of the Lower Volga region yielded the dating ranges of 91–122 ka (Th/U), and 84–130 ka (TL) (Shkatova *et al.*, 1989, 1994; Baryshnikov *et al.*, 1991). The r-subzone corresponding to the Blake episode was established in the early Khazarian deposits; it was the first time that the r-subzone was dated by both Th/U and TL methods, which yielded the age determinations of 89–117 ka (Shkatova, 1991). The well-preserved shells of the *Didacna* genus with distinct growth lines were thoroughly cleaned from the enclosing rock. A binocular microscope (×12.5) was used to control the quality of cleaning. Aragonite samples were obtained by using a dentist's drill with a steel cutter (diameter 0.5 mm). The consecutive and uninterrupted sampling covered the shell interval from the initial (spring) to the final (autumn) growth lines of the third (from the apex) annual ring. On the shell surface, it is marked by the second and third annual heels, which appeared due to the winter delay in the molluskan shell growth.

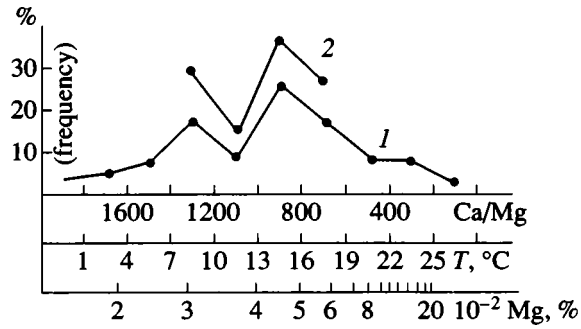


Fig. 1. Correlated variation curves for the optimum growth temperatures of the modern shells of the *Didacna* genus, magnesium content, and Ca/Mg ratios in aragonite of the late Khazarian shells: (*1*) distribution of the magnesium content and Ca/Mg ratios in aragonite of the late Khazarian shells of the *Didacna* genus (142 samples from 38 shells); (*2*) distribution of the mean temperatures of the most intensive growth of present shells of the *Didacna* genus and Cardiidae family (according to Gorbarenko *et al.*, 1975; Gorbarenko and Nikolaev, 1981).

The mineral composition of the shell substance was determined by X-ray diffraction analysis (analyst N.V. Kuznetsova) using a URS-50 diffractometer with filtered co-radiation at a rate of 2 deg/min, and under 15 kV voltage and 6 mA current power (external standard—NaCl). The obtained difractograms correspond to the standard aragonite (*Rentgenovskie* ..., 1965). According to available data (Parunin and Svitoch, 1981), the absence of secondary calcite indicates the preservation of the initial mineral and chemical composition of the *Didacna* shells. Magnesium content in the aragonite from successive zones of the shell growth varied from 0.02 to 0.12%, and, correspondingly, Ca/Mg ratios varied from 1600 to 400. The lowermost magnesium concentrations were measured in aragonite sampled near the annual heel (0.02–0.04%). The shell substance just in front of the heel accumulates during autumn, while that beside the heel accumulates during spring. During these seasons, the water temperature decreases, and salinity variations reach their maximum due to a sharp increase of the continental runoff in spring. Aragonite sampled from the central part of the annual ring yielded the maximum magnesium content (0.10–0.12%). Mollusk accumulates the shell substance in the central zone during summer, when the water with average salinity is intensively heated. It is likely that the magnesium content and Ca/Mg ratio in the aragonite of *Didacna* shells is mainly determined by seasonal temperature variations. Temperature growth caused an increase in the magnesium content, and hence, decrease of the Ca/Mg ratio.

The water salinity variations probably did not significantly influence the magnesium accumulation in the *Didacna* shells. Mollusks inhabiting the northern part of the paleosea were not subjected to water desalinization induced by the river runoff. For instance, the present average salinity of the northern Caspian Sea increases during the autumn–winter period and decreases during high water flooding by 2–3‰. Mixing of marine and fresh waters is accompanied by short-term salinity variations ranging from 2 to 12‰. The boundaries and area of the mixed waters change during the year depending upon the river runoff and wind direction. Long-term salinity variations (during the last 50 years the average annual salinity changed from 11.7 to 6.4‰) also depend upon freshwater influx (Bol'shakov, 1968; *Kaspiiskoe more*, 1986). Magnesium content in the shells of various species of the Ostreidae, Mytilidae, and Cardiidae families inhabiting seas with salinity ranging from 7 to 34‰ (*Fizicheskie* ..., 1988) shows that salinity does not influence the magnesium content in the shells of marine mollusks. In general, distribution of Ca/Mg ratios in aragonite of the *Didacna* shells have a bimodal character (Fig. 1). Forty eight percent of the studied aragonite samples (38 valves, 142 samples) demonstrate one maximum (800–1000), and 18% of the studied samples demonstrate a second maximum (1200–1400). Obviously, formation of the shell substance of the *Didacna* species with 0.03–0.07% of Mg occurred in a temperature range lesser than the annual water temperature variations. For instance, oxygen isotope thermometry (Gorbarenko *et al.*, 1975; Gorbarenko and Nikolaev, 1981) shows that in the Caspian Sea, the most intensive growth of the modern *Didacna* mollusks occurs under optimum temperatures, ranging from 10 to 16°C (Fig. 1). Since the growth adaptation to the temperature were identical to ancient and modern *Didacna*, we can correlate maxima on the variation curves demonstrating average temperatures, which affected the growth of mollusks, and Ca/Mg ratios in aragonite from their shells (Fig. 1). If 14.5 and 8.5°C correspond to the Ca/Mg ratios of 900 and 1300 respectively, then, as a first approximation, the linear function relating these parameters can be expressed by the following equation:

$$T = 28 - 0.015\mathrm{Ca/Mg}, \qquad (1)$$

where T is water temperature (°C) during accumulation of aragonite, and Ca/Mg is the calcium to magnesium ratio in aragonite.

Since mollusks of the *Didacna* genus accumulate aragonite under conditions of equilibrium exchange of oxygen isotopes between them and natural medium (Gorbarenko *et al.*, 1975; Gorbarenko and Nikolaev, 1981), the oxygen isotope composition in sea water can be evaluated by the equation of Epstein and Mayeda (1953) modified (Dorofeeva *et al.*, 1994) into the following form:

$$\delta_w = \delta_c - 15.1 + (117.9 + T/0.14)^{1/2}, \qquad (2)$$

where T is the water temperature (°C), δ_w and δ_c are the oxygen isotope composition in sea water and calcium carbonate of molluskan shell, correspondingly (‰). This equation is correct when δ_c is measured relative

to the PDB standard, and δ_w relative to the SMOW standard.

Thus, combined determination of the oxygen isotopic composition and Ca/Mg ratios in aragonite shells of the *Didacna* genus makes it possible to give quantitative estimations of both the temperature and oxygen isotope composition in ancient waters of the Caspian Sea. In addition, the oxygen isotope composition enables evaluation of the water salinity.

Distribution of the heavy-oxygen isotope ^{18}O in the Caspian Sea water is in good accordance with its salinity (Brezgunov *et al.*, 1987; Gorbarenko *et al.*, 1975; Gorbarenko and Nikolaev, 1974, 1981). Estimations of salinity (S, ‰) and oxygen isotopic composition (δ_w, ‰) resulted in the establishment of the mixing line of the fresh and marine waters in the northern Caspian Sea (Brezgunov *et al.*, 1987):

$$S = 1.15\delta_w + 15.0. \quad (3)$$

In a first approximation, the similar mixing line in the southern Caspian Sea corresponds to the following equation:

$$S = 2.12\delta_w + 14.9, \quad (4)$$

if we take into account that the average perennial salinity of the southern Caspian Sea is 13.2‰ (Bol'shakov, 1986; Kaspiiskoe more, 1986), its oxygen isotope composition corresponds to –0.8‰ on average (Gorbarenko and Nikolaev, 1974), and oxygen isotope composition of fresh waters with salinity of 0.0‰ is close to the oxygen isotope composition of the atmospheric precipitation. The latter in the Caspian Sea region is -7.0 ± 0.9‰. This value may be determined using the average air temperature (Panin *et al.*, 1991), and the previously established equation (Brezgunov *et al.*, 1982).

In the diagram of δ_w versus S (Fig. 2), the measured values of salinity and oxygen isotope composition in the northern Caspian Sea plot above the mixing line of fresh and marine waters (*3*). Evaporation results in isotopic fractionation and salinity growth (Brezgunov *et al.*, 1987). However, in the southern Caspian Sea, where evaporation was possibly the most intense, all the measured values plot below the mixing line of fresh and marine waters (*4*). In order to estimate the evaporation effect when calculating the water salinity by oxygen isotope composition, we can use the mean intermediate line of mixing:

$$S = 1.49\delta_w + 14.9, \quad (5)$$

where both fresh and marine waters are characterized by the mean oxygen isotope and salinity values (Fig. 2). Standard deviation of salinity data (Brezgunov *et al.*, 1987) from those calculated by (5) does not exceed 0.4, 0.9, and 1.8‰ for the salinity ranges of 13–10, 9–5, and 4–0‰, correspondingly.

Determination of the Ca/Mg ratios and oxygen isotope composition in the late Khazarian aragonite shells of the *Didacna* genus are given in the table together

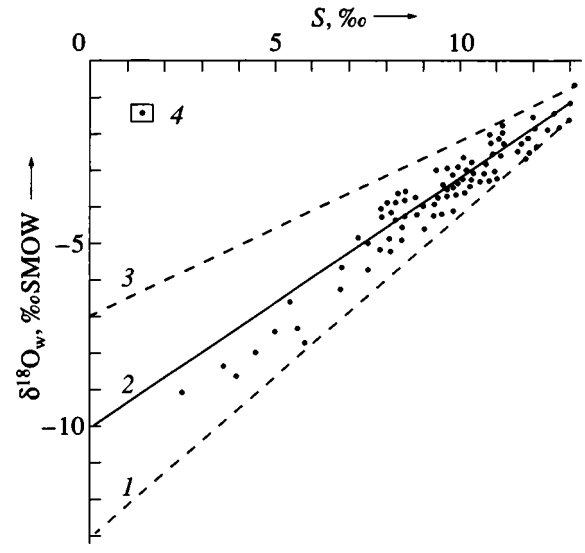


Fig. 2. Salinity (S) versus oxygen isotope composition (δ_w) in the Caspian Sea water.

(*1*) mixing line for fresh and marine waters of the northern Caspian Sea (Brezgunov *et al.*, 1987); (*2*) mixing line for fresh and marine waters with mean oxygen isotope and salinity values; (*3*) mixing line for fresh and marine waters of the southern Caspian Sea; (*4*) measured values of the oxygen isotope composition and water salinity in the northern Caspian Sea (Brezgunov *et al.*, 1987).

with the temperature, oxygen isotope, and salinity characteristics of the paleowaters calculated by equations (1), (2), and (5).

The mollusks of the *Didacna* genus, which yielded age determinations of 130–122 ka (the village of Vladimirovka), inhabited a brackish water basin. Its surface water temperatures were 14–16°C in spring and 21–22°C in summer. The surface water salinity was 8–10‰, and seasonal variations in this parameter did not exceed 2–3‰, comparable with the seasonal variations in the average salinity recorded in the open part of the northern Caspian Sea at present (*Kaspiiskoe more*, 1986). At that time, the salty waters of the central and southern Caspian Sea spread farther to the north. The oxygen isotopic composition of the water varied from –3 to –5‰, being 2–3‰ lighter than that of the present Caspian Sea. It was a transgressive stage in the evolution of this closed paleobasin caused by an increase in the river runoff. The thawing glaciers probably did not significantly contribute to the fresh water supply to the paleosea. Precipitation within the drainage area was formed, rather, by rains during warm seasons, and not by snow in winter period. Paleoclimate of the Lower Volga region was warm and humid.

Later, about 117–114 ka ago (the village of Lenino), climatic cooling occurred. Both spring and summer temperatures of paleowaters decreased by 5°C (table). The low intensity of summer insolation, simulated for the time period ranging from 114 to 116 ka (Berger and

Oxygen isotope composition (δ_o), magnesium content, and Ca/Mg ratio in the aragonite shells of the *Didacna* genus. Oxygen isotope composition (δ_w), temperature (T), and salinity (S) of the paleowaters

Locality (age, ka ago)	Substages of the oceanic scale	Species	Number of samples	Mg (%)	Ca/Mg	T (°C)	δ_o (‰) PDB	δ_w (‰) (SMOW)	S (‰)	Season of the year
The village of Seroglazovka	5d	*Didacna surachanica*	3	0.030	1345	7.5	−8.0	−10.0	0	Spring
				(0.002)*	(5)	(0.1)	(0.2)	(0.2)		
115 ± 5.8 (LU–932B)–$^{230}Th/^{234}U$		"	2	0.060	645	17.5	−8.5	−8.0	2.5	Summer
106 ± 6 (87–VOL) TL				(0.001)	(5)	(0.1)	(0.2)	(0.2)		
		D. crassa nalivkini	2	0.030	1485	6.0	−8.0	−10.5	0	Spring
				(0.002)	(190)	(2.5)	(0.2)	(0.8)		
		"	4	0.045	900	14.5	−4.8	−5.5	6.5	Summer
				(0.005)	(180)	(2.5)	(0.2)	(0.5)		
The village of Lenino		*D. surachanica*	2	0.030	1340	8.5	−3.8	−5.5	6.5	Spring
117 ± 7.5 (LU–925B)–$^{230}Th/^{234}U$				(0.002)	(90)	(1.5)	(0.2)	(0.5)		
114 ± 7 (87 VOL) TL		"	1	0.050	860	15.0	−2.5	−2.5	11.0	Summer
		D. crassa nalivkini	2	0.035	1250	9.5	−5.0	−6.5	5.0	Spring
				(0.002)	(150)	(2.0)	(0.2)	(0.5)		
		"	2	0.065	610	18.0	−3.2	−2.5	11.0	Summer
				(0.001)	(35)	(0.5)	(0.2)	(0.2)		
The village of Vladimirovka	5e	*D. surachanica*	2	0.050	785	16.5	−5.3	−5.0	7.5	Spring
				(0.002)	(40)	(0.5)	(0.2)	(0.2)		
122 ± 13 (LU–853B)–$^{230}Th/^{234}U$		"	4	0.100	385	21.0	–	–		Summer
130 ± 11 (87–VOL) TL				(0.005)	(70)	(1.0)				
		D. crassa nalivkini	3	0.040	985	13.5	−2.6	−3.0	10.5	Spring
				(0.002)	(70)	(1.0)	(0.7)	(0.3)		
		"	2	0.120	280	22.5	−6.2	−4.5	8.0	Summer

* Standard deviations from the mean values are given in brackets.

Loutre, 1991), confirm the reliability of the obtained paleotemperatures. The oxygen isotope composition of the atmospheric precipitation probably became lighter due to the next cooling, as indicated by the decreased content of the heavy ^{18}O isotope, which was about –6‰ in the spring paleowaters. At the same time, oxygen isotopic composition in the summer paleowaters became slightly heavier, up to –2.5‰. Seasonal salinity variations ranged from 5–6‰ in spring to 11‰ in summer. Such significant seasonal variations probably resulted from an increased share of the thaw water in the river runoff, and from a total decrease in the summer fresh water influx into the paleobasin. The cooling was probably accompanied by the redistribution of the annual precipitation, when the relative humidity increased in winter, and decreased in summer. This was the regressive stage in the evolution of the paleobasin, and the paleoclimate of the Lower Volga region became drier and colder than 130 ka ago.

During the period of 110–106 ka (the village of Seroglazovka), the cooling became more severe. Temperature of the paleowaters was 6–8°C in spring and 15–17°C in summer (table). The dominating influence of the continental thaw waters was responsible for the lighter oxygen isotope composition reaching –10‰ in spring waters. The afflux of the marine waters into the deltaic part of the basin was accompanied by a slight salinity increase up to 3–6‰ in summer. The Caspian Sea regression continued.

Thus, the warmest late Khazarian Sea existed during the Mikulino (Eemian) interglaciation (130–117 ka ago) corresponding to the 5*e* isotopic substage. The regres-

sive stage of the late Khazarian basin (117–106 ka) probably corresponds to the *5d* isotopic substage, i.e. to the beginning of the early Valdai, or early Visla glaciations.

The obtained data indicate that the global cooling, which started during the *5d* isotopic substage, corresponds to the Caspian Sea regression. Decrease in the total river runoff caused significant reduction of the paleobasin area. In its northern part, i.e., in the Lower Volga region, the share of the isotopically light waters sharply increased relative to the marine waters. The latter had the heaviest oxygen isotope composition within the isolated basin. Obviously, the established paleoclimatic events in the Caspian Sea area were synchronous to the global ones.

The results of our investigations show that the double carbonate thermometer can be used as a tool for obtaining quantitative paleoclimatic information on the Pleistocene transgressions of the inland Caspian Sea. In addition, it is useful in correlating glacial events in northeastern Europe with the marine Caspian events using known levels of the isotopically light thaw water influx, and in elaborating the continental climatic stratigraphic scale for the Pleistocene. Such progress would be extremely important for geological mapping and climatologic forecasts. The results are also important for the trans-Eurasian stratigraphic correlation in the ocean–continent system using the global paleoclimatic signal reference points.

The investigation was supported by the Russian Foundation for Basic Research, project no. 95-05-14617.

Reviewers A.I. Zhamoida and B.G. Pokrovskii

REFERENCES

Baryshnikov, G.F., Shkatova, V.K., and Shadrukhin, A.V., Discovery of Skull of the Bear *Ursus rossicus* in the Khazarian Deposits of the Lower Volga Region, in *Paleoteriologicheskie issledovaniya fauny SSSR* (Study on Fossil Mammalian Fauna of the USSR), *Tr. Zool. Inst. Akad. Nauk SSSR*, 1991, vol. 238, pp. 100–120.

Berger, A. and Loutre, M.F., Insolation Values for the Climate of the Last 10 Million Years, *Quat. Sci. Rev.*, 1991, vol. 10, no. 4, pp. 297–317.

Bol'shakov, V.S., Comparative Hydrological Characteristic of the Black Sea, the Sea of Azov, and the Caspian Sea, in *Ekologicheskaya biogeografiya kontaktnykh zon morya* (Ecological Biogeography of the Contact Zones in the Sea), Kiev: Naukova Dumka, 1968, pp. 3–20.

Brezgunov, V.S., Esikov, A.D., Ferronskii, V.I., *et al.*, Isotopic Composition of the Atmospheric Precipitation in Central and Eastern Europe, *IX Vsesouznyi simpozium po stabil'nym izotopam v geokhimii* (9th All-Union Symp. on the Stable Isotopes in Geochemistry), Moscow: Inst. Geokhim. Akad. Nauk SSSR, 1982, vol. 1, pp. 53–54.

Brezgunov, V.S., Nechaev, V.V., and Yakimova, T.V., Study on Water Exchange in the Northern Caspian Sea according to the Oxygen Isotope Composition of the Water, *Vodn. Resur.*, 1987, no. 1, pp. 155–161.

Dorofeeva, L.A., Prilutskii, R.E., and Badinova, V.P., A Possible Way to Reconstruct the Oxygen Isotope Composition of Marine Paleowaters, *Geokhimiya*, 1994, no 7, pp. 1030–1041.

Epstein, S. and Mayeda, T., Variations of ^{18}O Content of Water from Natural Sources, *Geochim. Cosmochim. Acta*, 1953, vol. 4, no. 5, pp. 213–224.

Fizicheskie i khimicheskie metody issledovaniya v paleontologii (Physical and Chemical Methods in Paleontology), Moscow: Nauka, 1988.

Gorbarenko, S.A. and Nikolaev, S.D., Oxygen Isotope Composition in Shells, in *Kompleksnoe izuchenie molluskov dlya tselei stratigrafii i paleogeografii* (Complex Investigations of Mollusks for Stratigraphy and Paleogeography), Moscow: Mosk. Gos. Univ., 1981, pp. 78–94.

Gorbarenko, S.A. and Nikolaev, S.D., Distribution of Oxygen Isotopes in the Caspian Sea Water, in *Kompleksnoe izuchenie Kaspiiskogo morya* (Complex Study of the Caspian Sea), Moscow: Mosk. Gos. Univ., 1974, vol. 4, pp. 122–125.

Gorbarenko, S.A., Nikolaev, S.D., and Popov, S.V., Factors Influencing the Oxygen Isotope Composition in Carbonates from the Caspian Molluscan Shells, in *Paleobiologiya donnykh bespozvonochnykh pribrezhnykh zon morya* (Paleobiology of the Bottom Invertebrates of the Offshore Zones), Vladivostok: Akad. Nauk SSSR, 1975, vol. 4, pp. 159–166.

Kaspiiskoe more: Gidrologiya i gidrokhimiya (The Caspian Sea: Hydrology and Hydrochemistry), Moscow: Nauka, 1986.

Martinson, D.G., Pisias, N.G., Hays, J.D., *et al.*, Age Dating and the Orbital Theory of the Ice Ages—Development of a High-Resolution—0 to 300000-Year Chronostratigraphy, *Quatern. Res.*, 1987, vol. 27, no. 1, pp. 1–29.

Nikolaev, S.D., Environmental Changes in the Cenozoic Oceans and Seas (According to Oxygen Isotope Data), *Doctoral (Geogr.) Dissertation*, Moscow: Moscow State Univ., 1986.

Panin, G.N., Dzyuba, A.V., and Osipov, A.G., Possible Reasons for the Evaporation Variations in the Caspian Sea Region during the Last Decades, *Vodn. Resur.*, 1991, no. 3, pp. 5–17.

Parunin, O.B. and Svitoch, A.A., Study of the Shell Mineral Composition, in *Kompleksnoe izuchenie mollyuskov dlya tselei stratigrafii i paleogeografii* (Complex Investigations of Mollusks for Stratigraphy and Paleogeography), Moscow: Mosk. Gos. Univ., 1981, pp. 66–78.

Prilutskii, R.E., Tsimberov, M.Ya., and Badinova, V.P., Analysis of the Oxygen and Carbon Isotope Composition in Carbonates Using Mass-Spectrometer MI 1330, in *Znachenie izotopnykh issledovanii dlya povysheniya effektivnosti i kachestva geologo-poiskovykh rabot* (Importance of the Isotopic Investigations for Further Improvement of Efficiency and Quality of Geologic Prospecting), Leningrad: Vses. Geol. Inst., 1986, pp. 80–89.

Rentgenovskie metody izucheniya i struktura glinistykh mineralov (X-Ray Methods and Structure of Clay Minerals), Moscow: Mir, 1965.

Shkatova, V.K., Hypothetical Climatic Sequence of the Main Sedimentation Epochs in the Caspian Sea during the Late Cenozoic, in *Pozdnechetvertichnaya istoriya i sedimentogenez okrainnykh i vnutrennikh morei* (The Late Quaternary

History and Sedimentology of the Marginal and Inland Seas), Leningrad: Nauka, 1979, pp. 112–115.

Shkatova, V.K., Dating of the Blake Excursion in the Upper Khazarian Deposits of the Lower Volga region, in *IV Vsesoyuzn. s"ezd po geomagnetizmu* (4th All-Union Conf. on Geomagnetism), Vladimir-Suzdal': Inst. Phiz. Zemli Akad. Nauk SSSR, 1991, pp. 51–53.

Shkatova, V.K., Arslanov, Kh.A., Shadrukhin, A.V., *et al.*, Stratigraphy and Age of the Khazarian and Khvalinian Deposits of the Lower Volga Region according to Radioisotopic and Physical Methods of Dating, in *Geokhronologiya chetvertichnogo perioda*, Tezisy dokl. Vsesoyuz. sovesh. (Quaternary Geochronology, Abstracts of the All-Union Conf.), Moscow: Akad. Nauk SSSR, 1989, p. 35.

Shkatova, V.K., Dorofeeva, L.A., and Prilutskii, R.E., Oxygen Isotope and Calcium–Magnesium Paleothermometry and the Caspian Sea Paleosalinity in Pleistocene, in *Vseross. soveshchanie po izucheniyu chetvertichnogo perioda* (The All-Russia Conf. on the Quaternary Investigations), Moscow, 1994, p. 226.

Stratigraphy and Geological Correlation, Vol. 4, No. 5, 1996, pp. 523–524. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 5, 1996, pp. 111–112.
Original Russian Text Copyright © 1996.
English Translation Copyright © 1996 by МАИК Наука/Interperiodica Publishing (Russia).

Awards of NAUKA Publishing Company for Best Publications in 1995

In 1995, NAUKA International Publishing Company (МАИК НАУКА) began to present awards for the best scientific works of the year, which were published in its periodical editions. Three of the prizes, as valuable as $1000 each, were awarded to the following series of publications in the journal *Stratigraphy and Geological Correlation*:

(1) A series of papers aimed at modeling the glaciation-free state of the biosphere inconsistent with its modern character: (a) "The Problem of the Warm Biosphere" by N.M. Chumakov (*Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 3, pp. 3–14); (b) "Paleogeography of the Mid-Cretaceous Period" by M.A. Zharkov, I.O. Murdmaa, and N.I. Filatova (*Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 3, pp. 15–41); and (c) "Climatic Belts of the Mid-Cretaceous Time" by N.M. Chumakov, M.A. Zharkov, A.V. Herman, M.P. Doludenko, N.N. Kalandadze, E.L. Lebedev, A.G. Ponomarenko, and A.S. Rautian (*Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 3, pp. 42–63). These researchers analyzed and reconstructed principal elements of the biosphere and their spatial distribution during four stages of the Mid-Cretaceous on the detailed basis of paleontological, lithological, and geochemical indicators. The authors were the first to validate that during this period the Earth was barren of permanent polar ice sheets and glacier caps. The inferred paleogeographic, chorologic, and paleoclimatic parameters of that time suggest that the global temperature on the earth was higher by several °C than at present, and a less contrast zonal distribution of biota was controlled then by specific geochemical processes, peculiar heat transfer, and the absence of psychrosphere in oceans. These factors were responsible for the unusual, still poorly understood features of the Cretaceous Period. The papers demonstrated that climate of the Mid-Cretaceous type was dominant in the past, while present climatic conditions were typical only of short intervals of geological history. On this basis, it was concluded that we should distinguish fundamentally different warm and cool states of the past biosphere. In their methodical and prognostic aspects, these investigation results are stimulating for many branches of geoscience, because they elucidate the application limits of uniformitarian approach and the parameters of the biosphere at the time of significant global warming.

(2) Two papers dedicated to the spatial structure of Proterozoic microbiota: (a) "The Main Peculiarities of the Environmental Distribution of Microfossils in the Riphean Basins of Siberia" by A.F. Veis and P.Yu. Petrov (*Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 5, pp. 97–129), and (b) "Facial-Ecological Structure of the Derevnya Formation Microbiota: Upper Riphean, Turukhansk Uplift, Siberia" by P.Yu. Petrov and A.F. Veis (*Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 5, pp. 13–41). Using data of detailed microphytological and sedimentological studies, these scientists depicted the facial-ecological structure of Riphean biota in all principal basins of that time. They demonstrated that the spatially ordered lateral distribution of fossil microorganisms is convenient for discriminating them into deep-water, "optimal" (moderately deep), transitional, and shallow-water groupings. The general structure of this community was controlled by the depth of the paleobasin and related hydrodynamic activity of sea water in the habitat zones of particular microfossil assemblages. It was evidenced that two opposite factors were responsible for the localization of the most diverse grouping of microorganisms in the optimal zone: the tendency of phototrophs to laterally migrate in the energetically favorable shoal shelf zones, and the hydrodynamic activity, growing along the paleobasin profile and thus restraining this expansion. The results of A.F. Veis and P.Yu. Petrov are important for evaluating the biostratigraphic potential of Riphean microfossils, and for solving a wide spectrum of problems concerning the paleoecology and paleobiology of the Precambrian.

(3) The paper "Sr Isotopic Composition in Riphean, Vendian, and Lower Cambrian Carbonates from Siberia" by I.M. Gorokhov, M.A. Semikhatov, A.V. Baskakov, E.P. Kutyavin, N.N. Mel'nikov, A.V. Sochava, and T.L. Turchenko (*Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 1, pp. 3–33). This paper describes a new technique to study the Rb–Sr systematics of carbonates with a higher precision. It also substantially extends the available data base with new precise determinations of Sr isotope composition in the Late Proterozoic sea water, and radically modifies the previous viewpoint on the variation curve of this parameter during the Middle–early Late Riphean (1300–850 Ma). The new eventual interpretation of the $^{87}Sr/^{86}Sr$ variation curve, which was plotted for the Riphean–Vendian interval by using newly obtained and previously published data,

revealed the main geodynamic and paleogeographic changes that influenced the bulk chemistry and Sr isotope composition of the global ocean. This demonstrated advantages of Rb–Sr systematics on carbonates in solving problems of evolution of abiotic components in the Proterozoic biosphere. In addition, the aforementioned scientific team correctly outlined admissible limits of applying Sr-isotopic chemostratigraphy to the Middle–Upper Riphean rocks. The work of Gorokhov *et al.* also contributed much to our general understanding of the late Precambrian evolution of Earth's outer geospheres.

The editorial board of *Stratigraphy and Geological Correlation* congratulates all the prize winners. We wish them further success and are confident that this promising start is only the begining.

Editorial board
of *Stratigraphy and Geological Correlation*

Subscribe to the journals from the Russian Academy of Sciences

Translated and Published by МАИК Наука/Interperiodica Publishing

Distributed Worldwide by INTERPERIODICA

Copy this form to mail or fax your order today

	TITLE	Volume	ISSN	ISSUES	RATE IN US DOLLARS US/CAN	INTERNATIONAL	YOUR ORDER
❑	Doklady Mathematics	53/54	Pending	6	$999	$1099	$ _____
❑	Entomological Review	76	0013-8738	9	$1535	$1765	$ _____
❑	Eurasian Soil Science	29	1064-2293	12	$1452	$1670	$ _____
❑	Geology of Ore Deposits	38	1075-7015	6	$699	$805	$ _____
❑	Geochemistry International	34	0016-7029	12	$1637	$1883	$ _____
❑	Geotectonics	30	0016-8521	6	$395	$410	$ _____
❑	Herald of the Russian Academy of Sciences	66	1019-3316	6	$785	$999	$ _____
❑	Izvestiya, Atmospheric and Oceanic Physics	32	0001-4338	6	$550	$565	$ _____
❑	Izvestiya, Physics of the Solid Earth	32	1069-3513	12	$580	$610	$ _____
❑	Journal of Communications Technology and Electronics	41	1064-2269	16	$1901	$2186	$ _____
❑	Journal of Computer and Systems Sciences International	35	1064-2307	6	$1518	$1749	$ _____
❑	Journal of Ichthyology	36	0032-9452	9	$1319	$1519	$ _____
❑	Laser Physics	6	1054-660X	6	$759	$875	$ _____
❑	Oceanology	36	0001-4370	6	$490	$505	$ _____
❑	Paleontological Journal	30	0031-0301	6	$985	$1135	$ _____
❑	Pattern Recognition & Image Analysis	6	1054-6618	4	$499	$575	$ _____
❑	Petrology	4	0869-5911	6	$699	$805	$ _____
❑	Polymer Science. Series A	38	0965-545X	12	$1889	$2175	$ _____
❑	Polymer Science. Series B	38	Pending	6	$715	$825	$ _____
	Both Series A & B. $200 discount				$2404	$2800	$ _____
❑	Proceedings of the Steklov Institute of Mathematics	212-215	Pending	4	$735	$815	$ _____
❑	Russian Journal of Inorganic Chemistry	41	0036-0236	12	$1955	$2249	$ _____
❑	Russian Journal of Physical Chemistry	70	0036-0244	12	$1955	$2249	$ _____
❑	Stratigraphy and Geological Correlation	4	0869-5938	6	$699	$805	$ _____
❑	Studies on Russian Economic Development	6	1075-7007	6	$459	$529	$ _____
❑	The Physics of Metals and Metallography	81/82	0031-918X	12	$1705	$1960	$ _____
❑	Thermal Engineering	43	0040-6015	12	$1089	$1255	$ _____
❑	Transactions of the Russian Academy of Sciences/Earth Science Sections	346-351A	0012-494X	9	$2079	$2390	$ _____

TOTAL _____

❶ Name _____
Institution _____
Address _____
_____
City _____ State _____
Zip/Postal Code _____ Country _____
Telephone (_____) _____

Delivery is not made until payment is received

To order by phone call **1 800 633-4931**

or (205) 995-1567 outside the US and Canada

❷ ❑ My payment for $ _____ is enclosed.

OR

❑ Bill me. My library's purchase order number is _____ .

❸ Send this order and payment to:

INTERPERIODICA

P.O. Box 1831

Birmingham, AL 35201-1831

Or fax this order form to (205) 995-1588

Order now for immediate delivery. All journals will be published in 1996!

МАИК НАУКА/INTERPERIODICA PUBLISHING

is pleased to present to the international scientific community simultaneous Russian- and English-language publication of the journals of the Russian Academy of Sciences

МАИК НАУКА (NAUKA International Academic Publishing Company), in cooperation with the Russian Academy of Sciences, publishes the results of research in all fields of modern science performed by leading scientists and scientific institutions from Russia, the CIS, and other countries. Simultaneous English translation of the journals is provided by INTERPERIODICA Publishing, the translation division of МАИК НАУКА. Today, scientists around the world have direct access to the most significant Russian research at the time it is first published in Moscow – at the time it is most relevant to the worldwide scientific community. In addition to more timely publication, readers benefit from more precise translations of each journal, provided by a carefully chosen team of scientific translators with direct access to the authors and editors. English versions of the journals published by МАИК НАУКА/INTERPERIODICA PUBLISHING are distributed worldwide by INTERPERIODICA, Plenum/Consultants Bureau, and the American Institute of Physics.

МАИК НАУКА 1996 volumes include the following titles:

- *Doklady Mathematics*
- *Entomological Review*
- *Eurasian Soil Science*
- *Geology of Ore Deposits*
- *Geochemistry International*
- *Geotectonics*
- *Herald of the Russian Academy of Sciences*
- *Izvestiya, Atmospheric and Oceanic Physics*
- *Izvestiya, Physics of the Solid Earth*
- *Journals of Communications Technology and Electronics*
- *Journal of Computer and Systems Sciences International*
- *Journal of Ichthyology*
- *Laser Physics*
- *Oceanology*
- *Paleontological Journal*
- *Pattern Recognition and Image Analysis*
- *Petrology*
- *Polymer Science, Series A*
- *Polymer Science, Series B*
- *Proceedings of the Steklov Institute of Mathematics*
- *Russian Journal of Inorganic Chemistry*
- *Russian Journal of Physical Chemistry*
- *Stratigraphy and Geological Correlation*
- *Studies on Russian Economic Development*
- *The Physics of Metals and Metallography*
- *Thermal Engineering*
- *Transactions (Doklady) of the Russian Academy of Sciences/Earth Science Sections*

Please direct all inquiries about the above journals to: **INTERPERIODICA**, P.O. Box 1831, Birmingham, AL 35201-1831. For faster service call toll-free (800) 633-4931 or (205) 995-1567 (outside US and Canada). Fax: (205) 995-1588.

- *Applied Biochemistry and Microbiology*
- *Biochemistry (Moscow)*
- *Biology Bulletin*
- *Colloid Journal*
- *Cosmic Research*
- *Doklady Biochemistry*
- *Doklady Biological Sciences*
- *Doklady Biophysics*
- *Doklady Botanical Sciences*
- *Doklady Chemical Technology*
- *Doklady Chemistry*
- *Doklady Physical Chemistry*
- *Glass Physics and Chemistry*
- *High Energy Chemistry*
- *High Temperature*
- *Human Physiology*
- *Inorganic Materials*
- *Instruments and Experimental Techniques*
- *Journal of Evolutionary Biochemistry and Physiology*
- *Journal of Analytical Chemistry*
- *Kinetics and Catalysis*
- *Lithology and Mineral Resources*
- *Microbiology*
- *Programming and Computer Software*
- *Protection of Metals*
- *Radiochemistry*
- *Russian Journal of Applied Chemistry*
- *Russian Journal of Bioorganic Chemistry*
- *Russian Journal of Coordination Chemistry*
- *Russian Journal of Developmental Biology*
- *Russian Journal of Ecology*
- *Russian Journal of Electrochemistry*
- *Russian Journal of General Chemistry*
- *Russian Journal of Genetics*
- *Russian Journal of Marine Biology*
- *Russian Journal of Organic Chemistry*
- *Russian Journal of Plant Physiology*
- *Russian Microelectronics*
- *Solar System Research*
- *Theoretical Foundations of Chemical Engineering*
- *Water Resources*

Please direct all inquiries about the above journals to: **Plenum/Consultants Bureau**, 233 Spring Street, New York, NY 10013. Phone: (212) 620-8471. Fax: (212) 807-1047. E-mail: Plenum@panix.com

- *Acoustical Physics*
- *Astronomy Reports*
- *Astronomy Letters*
- *Crystallography Reports*
- *Optics and Spectroscopy**
- *Physics – Doklady*
- *Physics of Atomic Nuclei*
- *Plasma Physics Reports*

Please direct all inquiries about the above journals to: **American Institute of Physics**, Circulation and Fulfillment Services, 500 Sunnyside Boulevard, Woodbury, NY 11797-2999 USA. Tel. (516) 576-2270, (800) 344-6902. Fax: (516) 349-9704.

**Optics and Spectroscopy*: Optical Society of America, 2010 Massachusetts Ave., NW, Washington, DC 20036-1023, Attn.: Publications Department. Tel. (202) 223-8130, (800) 582-0416. Fax: (202) 223-1096.

МАИК Наука/Interperiodica Publishing (International Academic Publishing Co. "Nauka")
Profsoyuznaya ul., 90, Moscow, 117864, Russia, Phone: 7 (095) 3361600; Fax: 7 (095) 336 0666, E-mail:compmg@maik.rssi.ru